USDA Forest Service
Research Paper RM-83
February 1972

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U. S. Department of Agriculture
Fort Collins, Colorado



# PHYSICAL CHARACTERISTICS AND UTILIZATION OF MAJOR WOODLAND TREE SPECIES IN ARIZONA

Roland L. Barger and Peter F. Ffolliott

## PREFACE

This report has been prepared principally for those interested in, involved in, or contemplating utilization of the major woodland tree species of Arizona. The report attempts to bring together, from widely scattered sources, available information relating to the stand and stocking characteristics, physical attributes, and utilization of the species. The influence of other land management activities upon resource availability, and implications for utilization, are discussed briefly in the final section.

The authors acknowledge the direct and indirect contributions of information from a multitude of sources, both published and unpublished, as reflected by credit references and the bibliography. Particularly significant were the contributions from the Utah Agricultural Experiment Station, College of Natural Resources, and Economic Research Center, Utah State University; the Northern Arizona University School of Forestry; and the USDA Forest Products Laboratory.

Detailed physical data have generally been excluded from the text throughout the report. Data describing in detail the resource, its characteristics, and its utilization will be found in the appendices, which also include a glossary of terms that may be unfamiliar to some readers.


## ABSTRACT

Woodland species, principally pinyon and juniper, cover over 51 million acres in Arizona and adjoining States. The occurrence, physical characteristics, and utilization potential of pinyon, juniper, and Gambel oak are reported here. Products for which they may be especially suited include veneer, particleboards, charcoal, pulp, and chemical extractives. In addition, pinyon is valuable for Christmas trees and nuts.

The report is a reference handbook of all available information relating to stand and stocking characteristics and physical and chemical properties of the species.


Key words: Woodland species, pinyon-juniper, forest products, wood properties.

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# Physical Characteristics and Utilization of Major Woodland Tree Species in Arizona

by

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# Physical Characteristics and Utilization of Major Woodland Tree Species in Arizona

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## INTRODUCTION

Woodland species occupy about one-fifth of the land area of Arizona, or more than three times the area of commercial forests (Spencer 1966). Although these species are of less commercial value than the saw log forests of higher elevations, they represent a vast potential forest resource. Since the earliest days of Spanish exploration and settlement, the woodland species have been a source of fuelwood, posts, poles, and some food (Fogg 1966, Hamilton 1965, Randles 1949, Reveal 1944). More recently they have gained attention as a potential source of raw material for such products as paper, particleboard, charcoal, extractives, and novelty items.

Four species comprise most of the Arizona woodland resource, and achieve sufficient size and form to encourage utilization for wood products. These major woodland species are common pinyon,[2] Utah juniper, alligator juniper, and Gambel oak. Utah juniper is associated with and occasionally replaced by a physically similar species, one-seed juniper, in parts of northern and east-central Arizona. This report presents information describing the occurrence, physical characteristics, and past, present, and potential uses of these species. Although much of the information is based upon studies conducted in Arizona, or on sample materials from north-central Arizona, it is broadly applicable to the four species throughout their range. Information relating to these species outside Arizona is included where applicable and desirable.

[2]*The common and botanical names of plants mentioned are listed on page 80.*

We have attempted to present directly comparable information for all species. Some of the woodland species have not been studied as extensively as others, however, and comparable data are frequently unavailable.

## THE MAJOR WOODLAND SPECIES

### Distribution

Pinyon, Utah juniper, alligator juniper, and Gambel oak are widely distributed across the western States. The pinyon-juniper type extends from New Mexico west into southeastern California (Soc. Amer. Forest. 1954) (fig. 1). Common pinyon and Utah or one-seed junipers make up the type composition through southern Colorado, New Mexico, Arizona, and eastern Utah. Singleleaf pinyon and Utah juniper are predominant in western Utah and Nevada. Singleleaf pinyon and other junipers form the type in California. Scattered stands of these pinyon and juniper species are also found in southwestern Texas and the Oklahoma Panhandle, and as far north as southwestern Wyoming and southern Idaho (Critchfield and Little 1966, Harlow and Harrar 1950).

There are 51 million acres of the pinyon-juniper type in Arizona and the adjoining States of New Mexico, Colorado, Utah, and Nevada (U.S. Forest Serv. 1958, p. 117), plus another 10 million acres in other western States. Over 12.2 million acres of the type occur in Arizona alone, containing an estimated 953 million cubic feet of pinyon and 1,040 million cubic feet of juniper (Spencer 1966).

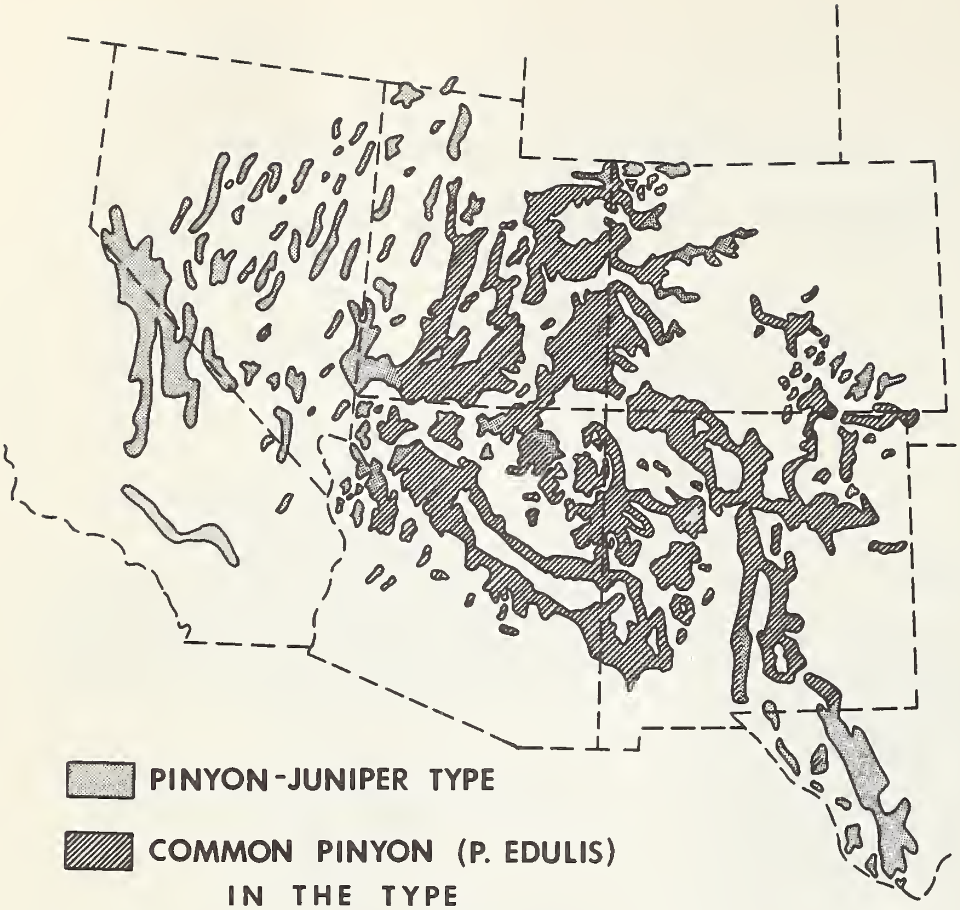



Figure 1.--General range of the pinyon-juniper type, and of common pinyon within the type, in southwestern United States.

Alligator juniper occurs from southwestern Texas through New Mexico and Arizona, while Gambel oak covers a somewhat wider range, extending into Colorado, Wyoming, Utah, and Nevada. Both species occur intermixed through much of the ponderosa pine type, as well as in the upper pinyon-juniper type. Gambel oak is found through practically all of the ponderosa pine type in Arizona, an area of 3.6 million acres.

### Occurrence and Silvical Characteristics

Woodland species in Arizona grow in both a true woodland vegetation type and as intermingling species in a commercial timber vegetation type. Species distribution is determined primarily by precipitation patterns; the bulk of the woodland species grows at lower elevations where precipitation is insufficient for commercial timber species (fig. 2). Localized variations are due to physiographic factors such as slope, aspect, and soil characteristics.

Patterns of occurrence and stand characteristics vary substantially between species. Pinyon and the junipers are found principally in the extensive pinyon-juniper woodland type, the largest single forest vegetation type in Arizona (fig. 3). The type typically occupies intermediate elevations from 4,500 to 7,500 feet (Little 1950). Pinyon and one or more species of juniper commonly grow intermixed in the type. Generally speaking, pinyon and alligator juniper are most common at the higher elevations of the type, pinyon and Utah juniper occur intermixed at middle elevations, and Utah juniper is predominant at lower elevations down to the short-grass rangeland (Arnold et al. 1964) (fig. 4). Both pinyon and Utah juniper also frequently form relatively pure stands. Pure juniper stands are characteristically open, whereas pure pinyon stands on better sites may be dense and forestlike. Alligator juniper rarely forms pure stands, but often exists as an intermingling species throughout the lower ponderosa pine type.

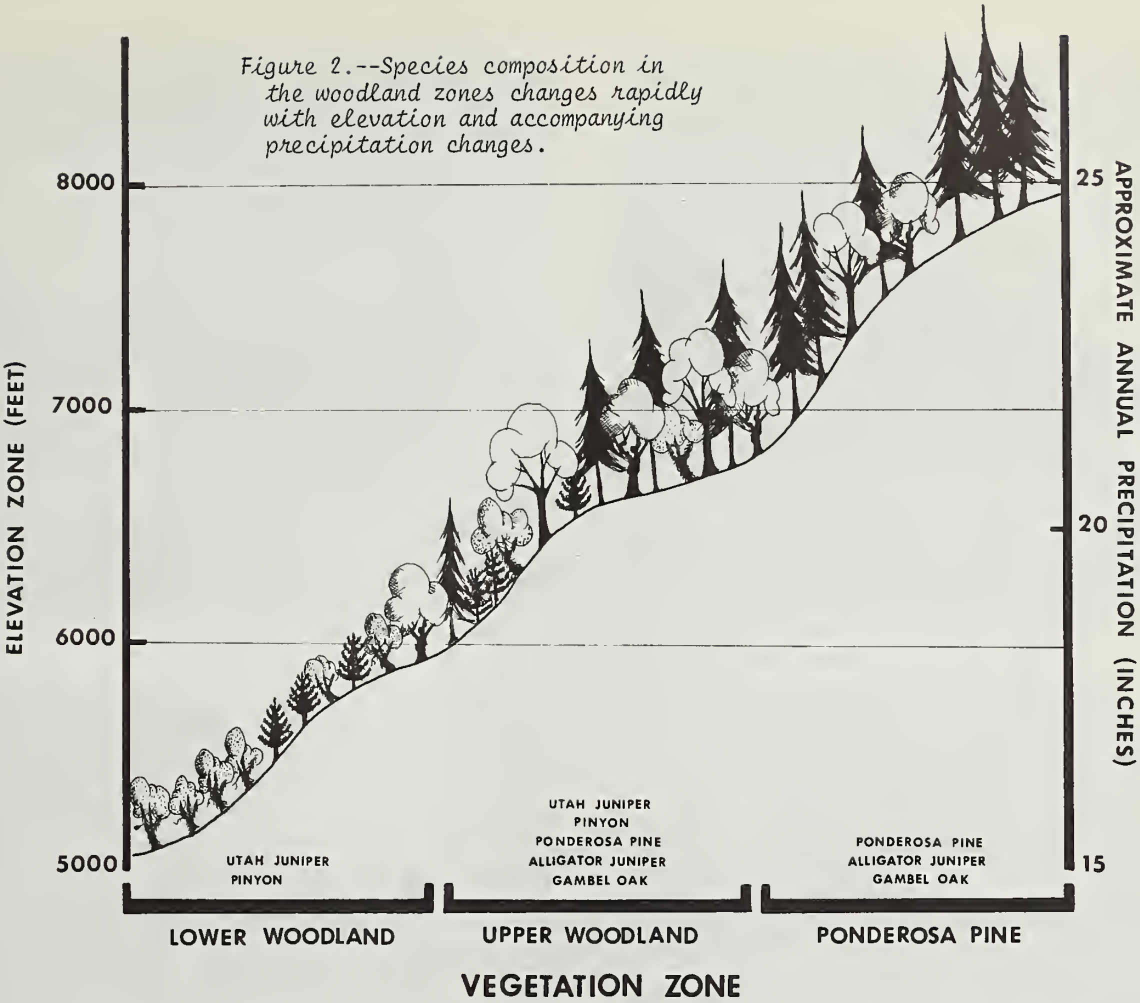



*Figure 2.--Species composition in the woodland zones changes rapidly with elevation and accompanying precipitation changes.*

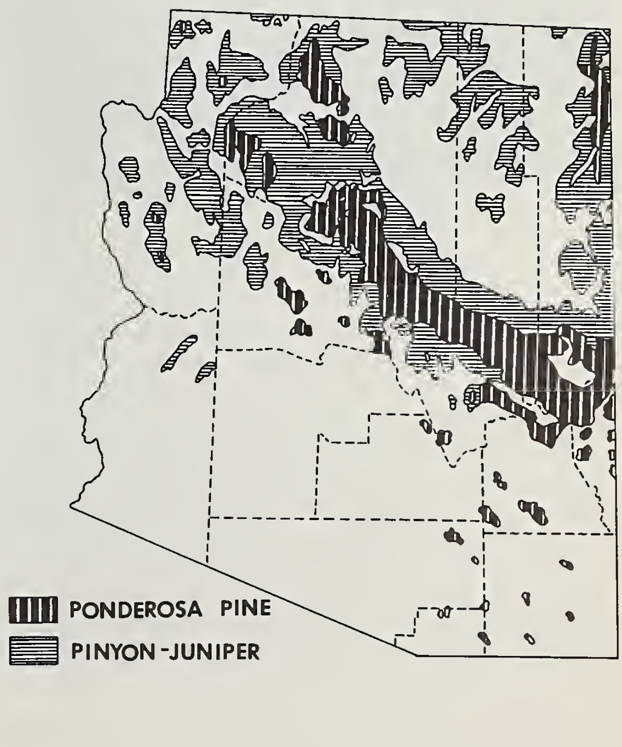



*Figure 3.--Location and extent of the pinyon-juniper and ponderosa pine forest types in Arizona.*


*Figure 4.--The occurrence of pinyon and the junipers ranges from relatively dense, pure stands of pinyon (A), to intermixtures of the species (B). At lower elevations Utah juniper forms extensive open stands (C). Alligator juniper occurs in both the pinyon-juniper type and through the lower pine type (D). Gambel oak occurs principally as an intermingling species in the ponderosa pine type.*

Below the Mogollon Rim, species composition of the pinyon-juniper woodland type differs from that found farther north. Two vegetation zones, referred to as upper and lower woodland zones, are recognized in the sub-Mogollon region of the Inland Southwest (Lowe 1961). The lower woodland zone, which extends up to approximately 5,900 feet elevation, contains primarily Utah juniper with occasional intermixed pinyon. The upper zone occupies elevations from 5,900 to 6,500 feet, and is commonly stocked with alligator juniper. Minor volumes of Utah juniper and pinyon are also occasionally included, and Gambel oak and ponderosa pine are found at the upper elevations of the zone.

Pinyon is a small pine tree rarely exceeding 35 feet in height and 24 inches in diameter

(U.S. Forest Serv. 1965). The trees are typically single stemmed, with a short straight trunk and many large branches forming a rounded, spreading crown (fig. 5). Open-grown trees tend to be shrubby, with little or no limb-free trunk. The common pinyon, sometimes referred to as Colorado pinyon, is the principal species of the tree found in the Southwest. Two very similar species, Mexican pinyon and singleleaf pinyon, occur in limited areas (Little 1950). The wood of pinyon is similar to that of other western pines—soft, even textured, and resinous.

Utah juniper, the most common juniper in Arizona, is also a small tree, usually less than 30 feet tall; it closely resembles one-seed juniper (fig. 6). Better trees may have a single, short trunk 1 to 2 feet in diameter, breast high (d.b.h.), but multiple stems extending from the ground or from a short basal trunk are also common. Open-grown trees tend to be bushy and multiple stemmed. The species has a soft, fine-textured wood with light brown heartwood and creamy white sapwood.

Alligator juniper, the largest of the western junipers, occasionally reaches 65 feet in height and 7 feet in d.b.h. (Little 1950). The tree commonly has a single short, heavy trunk, and a massive, spreading crown (fig. 7). Alligator juniper grows in mixture with pinyon and other junipers in the upper pinyon-juniper type, and as a minor intermingling species in the ponderosa pine type up to approximately 8,000 feet elevation. Many of the larger trees are found in the ponderosa pine type. Older, larger trees often exhibit dead strips up the trunk and extending along larger limbs. The wood is soft and fine textured, with reddish-brown heartwood and light sapwood. It has a strong characteristic "cedar" fragrance.

Gambel oak is widely distributed across the Southwest, both as a brush or shrub species and a tree species (Brown 1958, Little 1950). Although it typically forms shrubby thickets over much of its range, it also forms respectable trees under favorable conditions (Amer. Forest. Ass. 1956). Gambel oak trees occur principally as a minor or intermingling species in the ponderosa pine type. In the lower pine type, Gambel oak may make up as much as 25 to 30 percent of the stand. At elevations below the ponderosa pine type, it is occasionally

Figure 5.--A typical mature pinyon, with large branches and spreading crown.

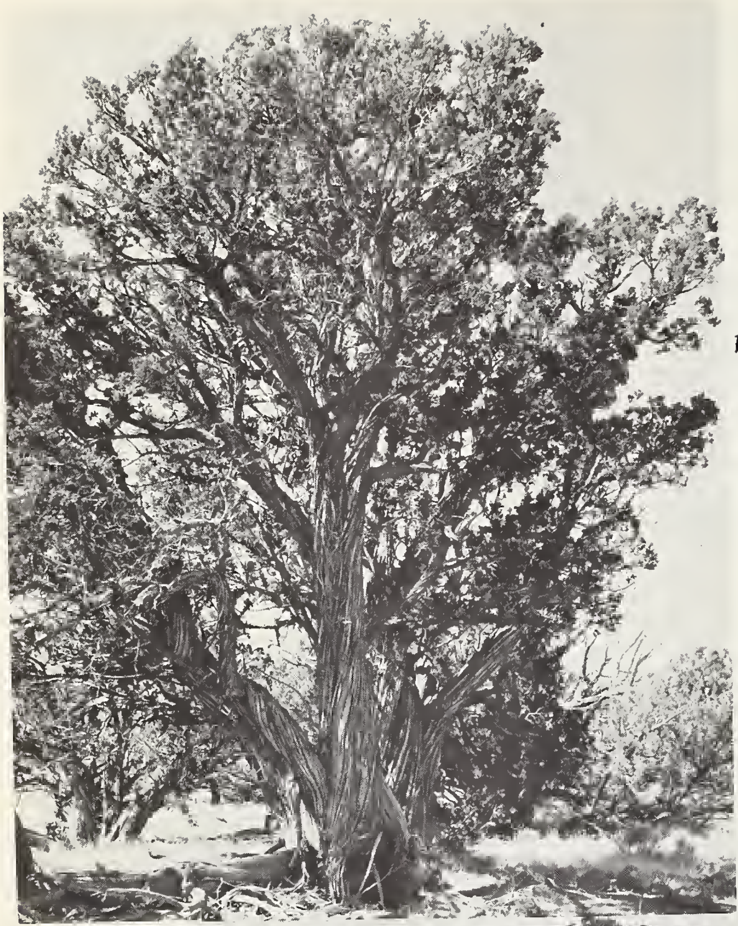


Figure 6.--
Mature Utah juniper is often multiple stemmed and has a dense, spreading crown.

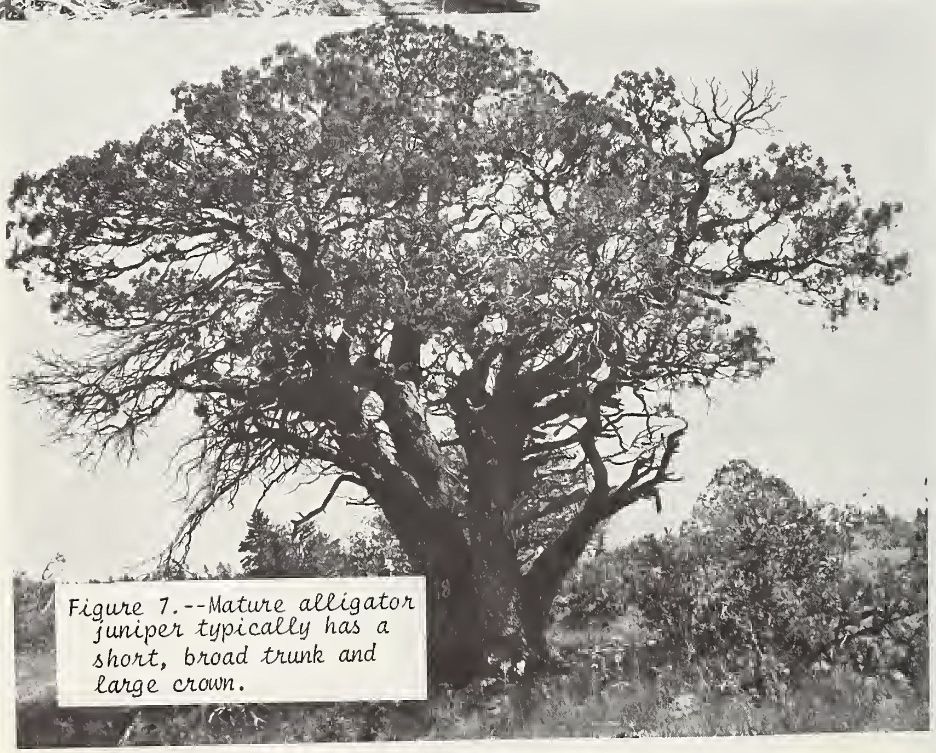


Figure 7.--Mature alligator juniper typically has a short, broad trunk and large crown.

found with pinyon and juniper, particularly along creek bottoms and water courses.

Gambel oak trees range from 20 to 70 feet in height and up to 3 feet in d.b.h. (fig. 8). The trees grow both singly and in scattered clumps. On poorer sites, short irregular trunks and large, spreading, limby crowns characterize the trees. On good sites, however, straight well-formed stems are common. The species sprouts prolifically, and tends to spread following fire, cutting, or other disturbance (Brown 1958). The wood of Gambel oak is hard, heavy, and similar in appearance to that of the eastern white oaks.

## Stand, Stocking, and Growth Characteristics

Stand and stocking characteristics of each of the major woodland species vary considerably. Some, but not all, of the species occur in each of the vegetation zones previously discussed—pinyon-juniper woodland, sub-Mogollon woodland zones, and lower ponderosa pine type. Figures 9 through 12 illustrate typical stand and stocking conditions in the four vegetation associations or zones. Detailed data describing stand, stocking, and growth characteristics are in appendix B, tables 20 through 29; tree volume tables are included as tables 30 through 33.

*Figure 8.--Mature Gambel oak trees occur as an intermingling species in the ponderosa pine type. Good sites support large, well-formed trees. The Gambel oak tree pictured in the inset is 38.3 inches in diameter, 76 feet tall, and has an average crown diameter of 40 feet.*

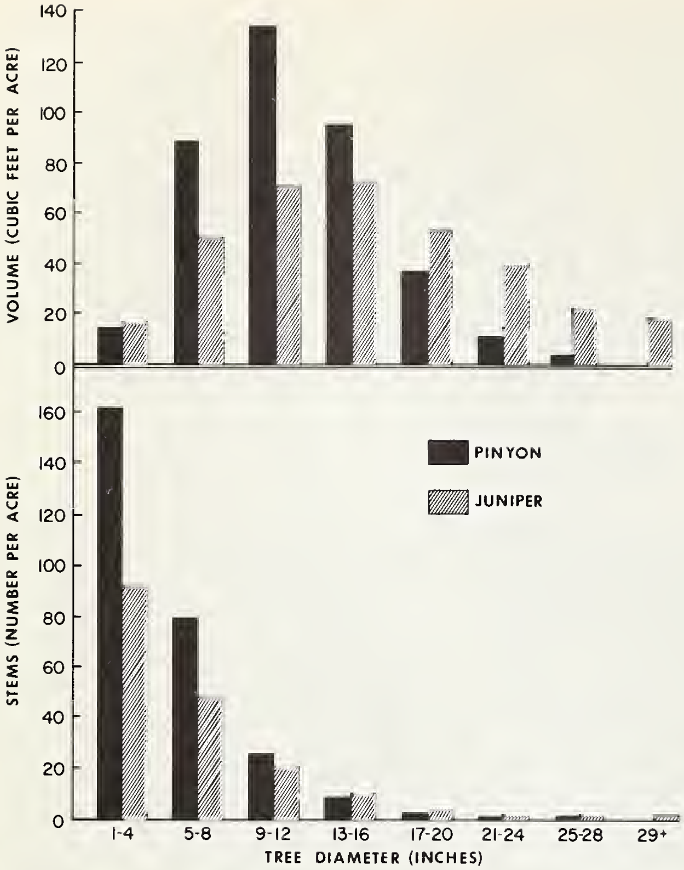



*Figure 9.--Number of trees and volume per acre of woodland tree species in the pinyon-juniper type in northern Arizona and New Mexico. (Adapted from Howell 1940.)*

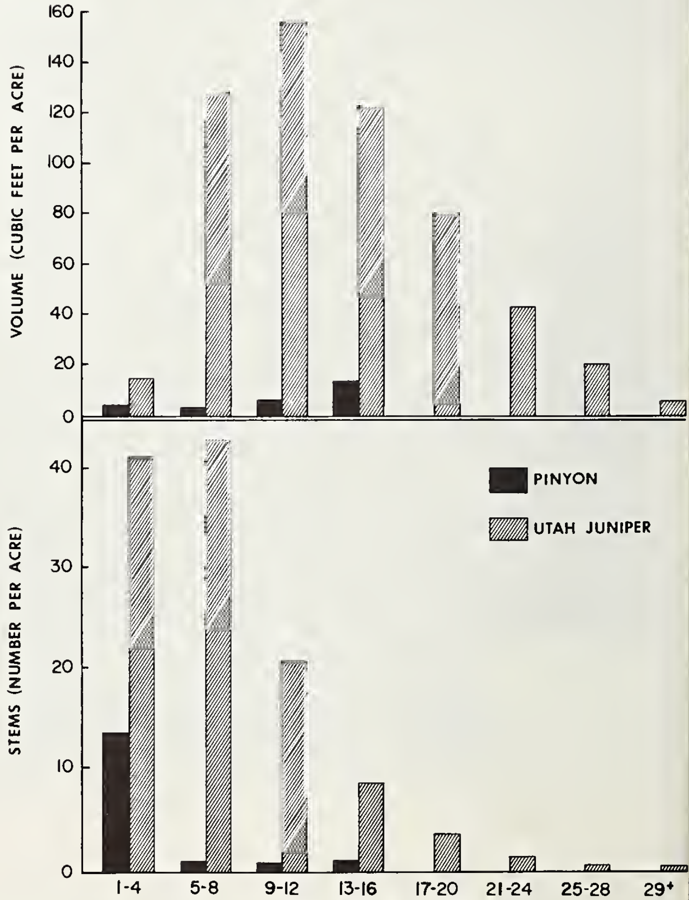



*Figure 10.--
Number of trees and volume per acre of woodland tree species in the lower woodland zone below the Mogollon Rim.*

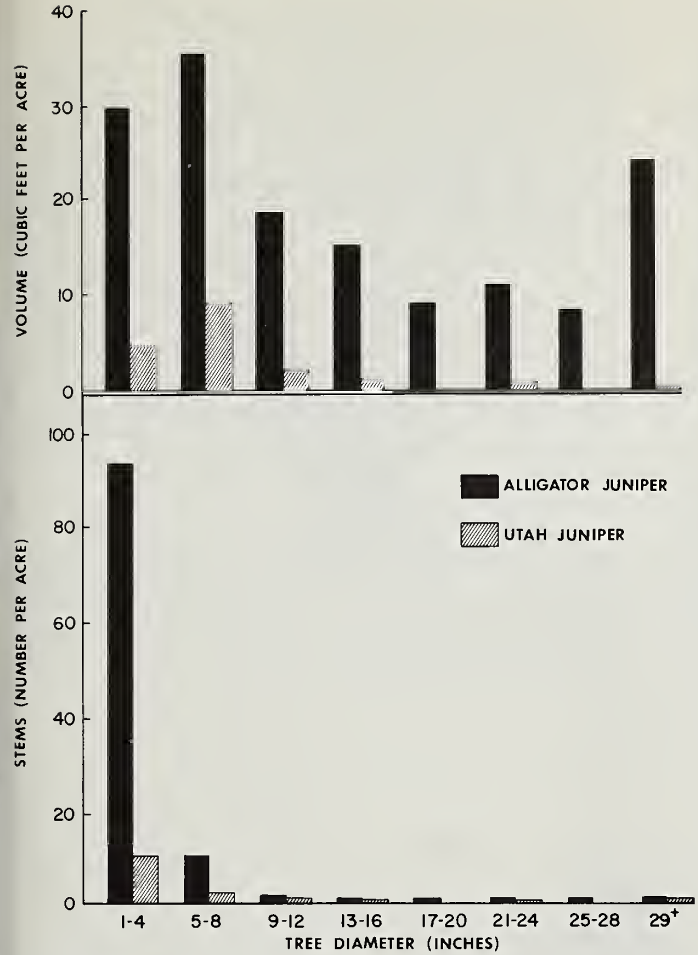



*Figure 11.--*
*Number of trees and volume per acre of woodland tree species in the upper woodland zone below the Mogollon Rim. In addition to the species illustrated, small amounts of ponderosa pine, pinyon, and Gambel oak occur in the zone.*

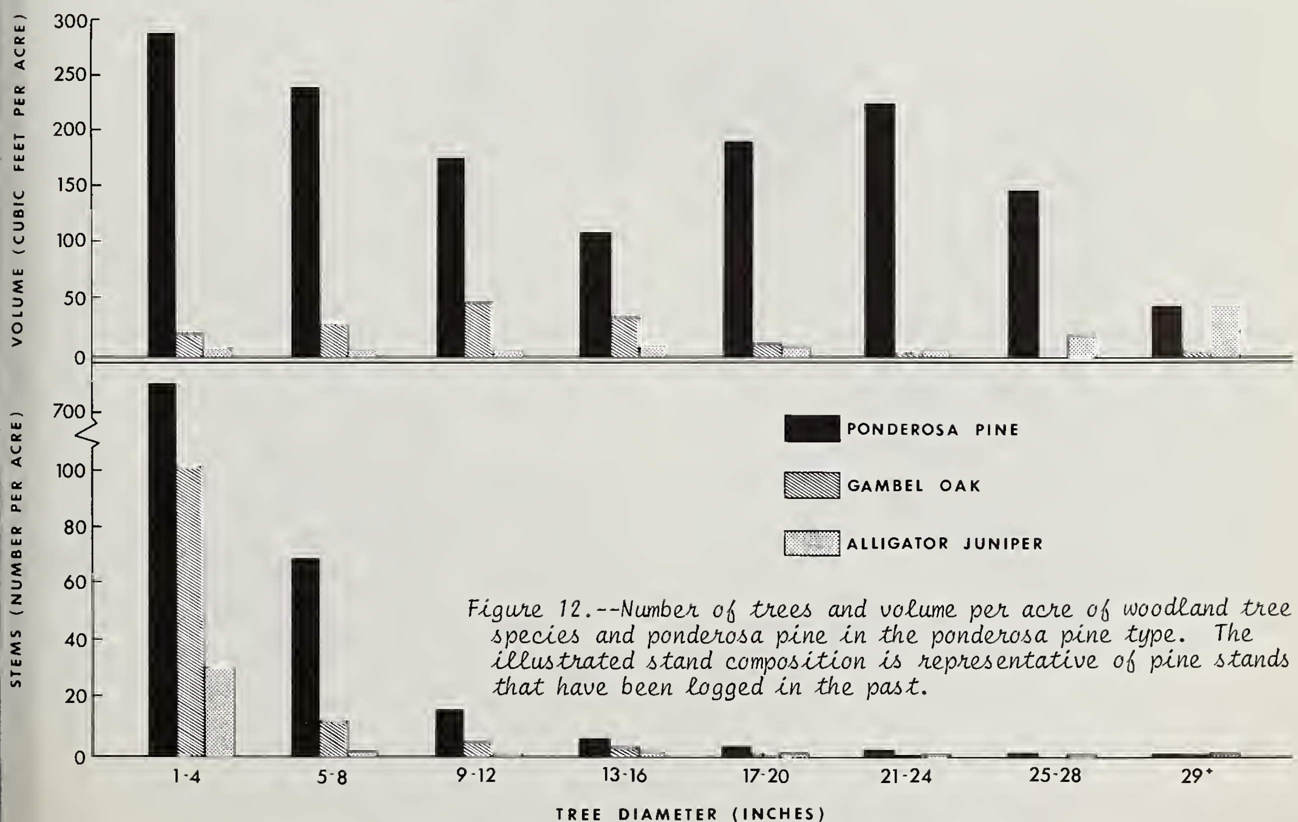



*Figure 12.--Number of trees and volume per acre of woodland tree species and ponderosa pine in the ponderosa pine type. The illustrated stand composition is representative of pine stands that have been logged in the past.*

**Pinyon**

Howell (1940) reported an average of 282 pinyon trees per acre on sample plots representing the range of size and form characteristics typical of pinyon-juniper woodlands in northern Arizona and New Mexico (fig. 9). Almost 90 percent of the stems were less than 10 inches in diameter at stump (1 foot) height. Pinyon in the stand accounted for 44 square feet of basal area per acre, and contained 393 cubic feet or 5.9 cords of wood per acre. Gross annual growth of pinyon in the stand averaged 6 cubic feet per acre, approximately 1.5 percent of existing gross volume.

Below the Mogollon Rim, pinyon occurs primarily as a minor species in the lower woodland zone (fig. 10). Pinyon in the stand averages 16 stems per acre, exclusive of reproduction. Volume averages 23 cubic feet per acre, mostly in trees 9 inches and larger in d.b.h. Gross annual increment is 0.2 cubic foot per acre, or 1 percent of existing gross volume.

Pinyon grows relatively slowly, and rarely exceeds 0.75 inch diameter growth per decade. Howell (1940) reported decadal growth rates ranging from 0.7 inch in young pinyon trees to 0.4 inch in older trees. Reveal (1944) reported diameter growth of approximately 1 inch per decade for the first 100 years, decreasing to 0.2 inch at 200 years, in singleleaf pinyon in Nevada.

Young pinyon trees grow more rapidly than older trees, and also grow more rapidly than associated juniper species in both diameter and height (Howell 1940, Jameson 1965). Growth rates are similar in larger trees of the two species. Because of the early growth advantage, however, pinyon trees maintain consistently greater cubic volume growth than juniper trees of comparable age.

Jameson (1965) observed that trees in pinyon-juniper stands grow in three distinct distribution patterns. The recognized patterns include single tree, groups of two or more trees of about equal size, and small trees growing as understory to larger trees.

## Utah Juniper

The junipers, principally Utah and one-seed, make up approximately half of the stand in the pinyon-juniper type in the northern and western parts of the State (Arnold et al. 1964). One-seed juniper occurs across the central and east-central area above the Mogollon Rim. The two species are physically equivalent for all practical utilization considerations. Howell (1940) reported an average of 180 juniper trees per acre on pinyon-juniper woodland plots in northern Arizona and New Mexico (see fig. 9). Juniper made up 46 square feet of basal area per acre, and contained 351 cubic feet or 5.5 cords of wood per acre. Diameter growth was slow, seldom exceeding 0.5 inch per decade. Gross annual increment averaged 3.5 cubic feet per acre.

Utah juniper is found in both upper and lower woodland zones below the Mogollon Rim (figs. 10, 11). In the lower zone, Utah juniper averages 119 stems per acre, exclusive of reproduction, and contains 572 cubic feet per acre. Gross annual increment is 5.7 cubic feet per acre, or approximately 1 percent of existing gross volume. Utah juniper occurs as a minor species in the upper woodland zone, averaging 15 stems and 17 cubic feet per acre, exclusive of reproduction.

Herman (1953) and Myers (1962) reported a net annual increment of 2.9 cubic feet per acre in a Utah juniper stand that contained all size classes. Gross annual increment and ingrowth increased during a 20-year study period, but because mortality also increased, net increment was relatively consistent. The volume of most individual trees increased less than 1 cubic foot during the 20-year study period.

Reveal (1944) described mature virgin Utah juniper in Nevada as commonly single stemmed, whereas immature trees in second-growth stands were frequently multiple stemmed. In typical singleleaf pinyon-Utah juniper stands, total stems per acre ranged from 52 in young open stands to 380 in mature dense stands. Volume varied from 73 to 1,440 cubic feet per acre. Because of the multi-stemmed character of many second-growth trees, second-growth stands usually contained more volume than virgin stands of the same density. Gross annual increment, which increased with stand age and density, ranged from 2.8 cubic feet per acre in immature open stands to 45.6 in mature dense stands.

**Alligator Juniper**

Alligator juniper is the predominant tree species in the sparsely stocked upper woodland zone below the Mogollon Rim (see fig. 11). Significant volumes of the species also occur at the lower elevations of the ponderosa pine type (fig. 12). Occasional scattered alligator juniper trees can be found throughout much of the pinyon-juniper and pine type.

Alligator juniper is frequently multiple stemmed because of base or root sprouting. To facilitate stem measurements, three tree forms were recognized and measured as follows: (1) single stem, measured at breast height; (2) multi-stemmed form, forking at groundline, with each fork considered an individual stem and measured at breast height; (3) multi-stemmed form, forking between groundline and breast height, measured as a single stem at 2 feet height or just below fork swell.

Alligator juniper in the upper woodland zone averages 108 stems per acre, exclusive of reproduction, with much of the stocking in the lower diameter classes. Volumes range from 100 to 250 cubic feet per acre, and average 150. Gross annual increment is 3.1 cubic feet per acre, or approximately 2 percent of existing gross volume.

In the lower elevations of the ponderosa pine type, alligator juniper averages 35 stems per acre, exclusive of reproduction. Volumes average 109 cubic feet per acre, generally well distributed among the existing size classes. Gross annual increment amounts to 2.7 cubic feet per acre, or 2.5 percent of existing volume. Growth percent is somewhat higher than in the woodland zone, probably due to increased precipitation; because of lower stand volumes, however, volume increment is less.

Diameter growth of individual alligator juniper trees in both vegetation zones ranges between 0.5 and 0.7 inch per decade, and is highest in the smaller diameter classes. Height growth is slow throughout the life span of the tree.

## Gambel Oak

Gambel oak forms brush or shrub thickets over much of its range. Brown (1958) reported the average mature stem in such stands in west-central Colorado to be 3 inches in stump diameter and 13 feet in height. Most stems were less than 80 years old, which indicated early mortality.

In addition to the brush form, however, Gambel oak occurs extensively throughout the ponderosa pine type as a tree (see figs. 8, 12). Large, well-formed trees are common on the better sites. The number of stems and volume per acre vary, with a greater number of stems but less total volume at lower elevations. At elevations below 7,000 feet, Gambel oak averages 75 stems per acre, exclusive of reproduction. Over 70 percent of these trees are less than 5 inches in diameter. Stands above 7,000 feet elevation average 56 stems per acre, with 60 percent less than 5 inches in diameter. Volumes average 195 cubic feet per acre at the lower elevations, and 290 at higher elevations. The greater volume above 7,000 feet elevation is due to the higher proportion of stems in larger size classes. The gross annual increment of Gambel oak within the pine type averages 3.4 cubic feet per acre, or about 2 percent of the existing gross volume.

Diameter growth of individual Gambel oak trees ranges from 0.5 to over 0.6 inch per decade. Height growth is rapid in young trees, but declines as the tree matures. Although heart rot caused by Polyporus dryphilus is common in the species (Hedgcock and Long 1914), it does not appear to influence either diameter growth or crown vigor.

## PHYSICAL PROPERTIES OF THE WOODS

Opportunities for utilizing the woodland species depend in part upon such physical properties of the woods as weight or density, mechanical strength, shrinkage characteristics, and visual features such as texture and color. Some knowledge of these physical properties and their variability is necessary for evaluating utilization possibilities.

Mechanical strength characteristics are important for uses in which members are, or may be, under load: posts, poles, ties, and structural timbers, for example. For use in furniture, novelties, or smaller turned or shaped products, hardness, texture, color, fragrance, shrinkage, and finishing characteristics may be of primary importance. Physical characteristics such as density and fiber length affect the yield and quality of chemically derived products such as charcoal and pulp.

The characteristic form and size of trees of each species also help determine the uses for which the wood may be suitable. Relatively large, uniform stems are required for the production of standard lumber, large timbers, or commercial poles. The woodland species do not generally produce stems suitable for such products. Many other products can be produced, however, from the smaller, more irregular stems.

### Specific Gravity

Specific gravity or density is the simplest and most useful single index to suitability of wood for many uses. Specific gravity is closely correlated with the mechanical strength of wood, and determines to a large extent the yield of products such as pulp and charcoal. It provides a means of estimating strength, shock resistance, and hardness. The variability in specific gravity also indicates the variability to be expected in physical properties.

To obtain an adequate measure of specific gravity, full-length increment cores were collected from a random sample of approximately 50 trees of each species. The sample represents a range of site and growth conditions that extends from the ponderosa pine-woodland species intermixture down to the sub-Mogollon woodland zones.

The woods of woodland species contain appreciable quantities of extractive chemicals. Since most strength characteristics and product yields are a function of cell wall material, specific gravity based on extracted wood is a better index of such properties. To determine extractive content and extracted specific gravity, extractives were removed from the sample increment cores. An ethyl alcohol-benzene solvent and hot water were used successively to remove extractives.[3] Specific gravity was determined for the cores both before and after extraction (table 1) by analytic procedures developed by the U. S. Forest Products Laboratory (U. S. Forest Serv. 1956). Specific gravity is a direct measure of the density of wood, normally expressed in pounds per cubic foot of unextracted wood (fig. 13).

[3] *Core extractions were performed by procedures developed by Professor Glenn Voorhies, Northern Arizona University, Flagstaff, with extraction equipment in the NAU Wood Technology Department.*

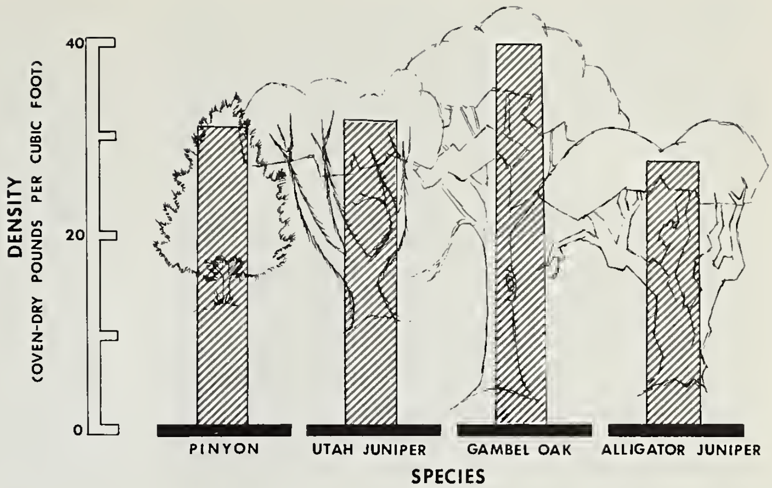
**Table 1. — Specific gravity of unextracted and extracted increment cores of woodland tree species[1]**

| Species | Unextracted | | | Extracted | | |
|---|---|---|---|---|---|---|
| | Range | | Mean | Range | | Mean |
| | Maximum | Minimum | | Maximum | Minimum | |
| Pinyon | 0.624 | 0.430 | 0.506 | 0.580 | 0.405 | 0.484 |
| Utah juniper | .682 | .439 | .511 | .605 | .390 | .466 |
| Alligator juniper[2] | .533 | .372 | .453 | .486 | .356 | .426 |
| Gambel oak[2] | .706 | .569 | .634 | .672 | .495 | .567 |

[1]Based on ovendry weight and green volume. Detailed specific gravity information for all species is included in appendix C, table 34.

[2]Specific gravity of unextracted wood from Barger and Ffolliott (1964, 1965).

Figure 13.--Density of unextracted wood of four woodland tree species.




### Strength and Related Properties

Strength includes all of the properties that enable wood members to resist a variety of loads or forces. Strength properties can be determined directly through tests of small wood samples, or they can be estimated from specific gravity. Strength characteristics determined from actual mechanical tests are available for pinyon, alligator juniper, and Gambel oak (table 2). These test values may be used to calculate working stresses, load-carrying capaci-

Table 2. — Strength properties of the air-dry wood of three woodland species (Markwardt and Wilson 1935)[1]

| Property | Unit of measure | Pinyon | Alligator juniper | Gambel oak |
|---|---|---|---|---|
| Static bending strength: | | | | |
| Stress at proportional limit | Lb./sq. In. | 5,600 | 5,400 | 5,200 |
| Modulus of rupture | Lb./sq. in. | 7,800 | 6,700 | 8,500 |
| Modulus of elasticity | M lb./sq. in. | 1,140 | 650 | 680 |
| Total work | In.-lb./cu. In. | 6.1 | -- | 13.3 |
| Compressive strength: | | | | |
| Maximum crushing strength, parallel to grain | Lb./sq. in. | 6,400 | 4,120 | 5,200 |
| Stress at proportional limit, perpendicular to grain | Lb./sq. In. | 1,520 | 1,700 | 2,070 |
| Hardness: | | | | |
| End | Lb. | 920 | 1,290 | 2,030 |
| Side | Lb. | 860 | 1,160 | 1,440 |

[1]All values are adjusted to a uniform air-dry condition of 12 percent moisture content. Detailed strength properties for both green and air-dry wood of the woodland species are included in appendix C, tables 35 and 36.

ties, and similar values (Markwardt and Wilson 1935, U. S. Forest Serv. 1935).

Index values describing major strength and physical properties may be useful in comparing the properties of one wood with another, or in choosing a wood outstanding in some particular property. Index values for woodland species (table 3) are based on combined strength values representing each of six major properties. For comparative purposes similar information is shown for two common commercial species, ponderosa pine and eastern redcedar.

Many strength and associated physical properties of wood are closely related to specific gravity. Empirical equations expressing the relationship of specific gravity to other physical properties have been developed from available data by the Forest Products Laboratory (Markwardt 1930, U. S. Forest Serv. 1956). Since the equations are based on a large volume of data, predicted strength values may be more reliable than actual strength tests on a small number of samples. Although specific gravity of unextracted wood is commonly used in such computations, values for extracted wood may yield more accurate results. Calculated strength values based on specific gravity of both unextracted and extracted increment cores, for green and air-dry wood of the four woodland species, appear in appendix C, table 36.

### Factors Affecting Strength

The strength values presented are based upon, or calculated for, clear wood specimens. Defects such as knots, decay, or irregular grain will affect many, but not all, of the strength properties of the wood. Knots, for example, have little effect upon compressive strength or stiffness.

Strength may also vary due to growth rate, growth conditions peculiar to the tree or locality, or any other factor that commonly influences specific gravity. Strength may even vary between trees of the same species growing in the same locality, as demonstrated by the range of specific gravity (see table 1) encountered in a small geographic area. For many species, specific gravity also decreases with height in the tree, resulting in stronger wood near the butt of the tree, and weaker wood near the top. Juvenile wood near the pith is often more rapidly grown and less dense than wood from other parts of the tree, which results in weaker wood. Both the pinyon species and the juniper species hybridize occasionally, adding the possibility of inherent variation due to genetic strain.

Moisture content has a pronounced effect upon most strength properties, as indicated by the comparative strength figures for green

Table 3. — Average comparative index[1] of properties of the clear wood of selected woodland species and two common commercial species (Markwardt 1930)

| Property | Pinyon | Alligator juniper | Gambel oak | Ponderosa pine | Eastern redcedar |
|---|---|---|---|---|---|
| | | | Comparative index | | |
| Bending strength | 60 | 63 | 70 | 65 | 67 |
| Compressive strength | 75 | 76 | 67 | 69 | 87 |
| Stiffness | 108 | 60 | 78 | 112 | 80 |
| Hardness | 73 | 107 | 137 | 41 | 81 |
| Shock resistance | 65 | 79 | 78 | 58 | 114 |
| Volumetric shrinkage | 99 | 73 | 121 | 97 | 78 |

[1]The numbers are index values based upon a weighted combination of specific strength values related to each of the six essential physical properties. Strength tests of both green and air-dry material were used; the final index values represent a condition of approximately 20 percent moisture content.

and air-dry wood. Most strength properties increase rapidly as wood dries below the fiber saturation point, although the various strength properties are not equally affected. Some properties, such as shock resistance, may actually decrease as wood dries. Average variations in physical and mechanical properties due to random variation in a species, and due to changes in moisture content, have been estimated (Markwardt and Wilson 1935) and are included in appendix C, table 35.

### Shrinkage Characteristics

Wood shrinks when it dries below the fiber saturation point of 25 to 30 percent moisture content. Normal wood shrinks a substantial amount transversely, generally expressed as radial (across rings) and tangential (parallel to rings) shrinkage. Larger differences between radial and tangential shrinkage indicate a greater tendency to check and cup during drying. Percent shrinkage values from green to ovendry condition (table 4) are about twice the shrinkage that will occur between green and an average air-dry condition of 12 to 15 percent.

Table 4. — Shrinkage characteristics of the wood of selected woodland species and ponderosa pine (adapted from Markwardt and Wilson 1935)

| Species | Shrinkage property | | |
|---|---|---|---|
| | Radial | Tangential | Volumetric |
| | Percent | | |
| Woodland: | | | |
| Pinyon | 4.6 | 5.2 | 9.9 |
| Alligator juniper | 2.7 | 3.6 | 7.8 |
| Gambel oak | 4.1 | 7.2 | 12.5 |
| Ponderosa pine | 3.9 | 6.3 | 9.6 |

## UTILIZATION—PAST AND POTENTIAL

Utilization of the woodland species has largely been restricted to use for fuelwood and fenceposts. The species represent a sizable wood fiber resource, however, that is potentially useful in the manufacture of products such as charcoal and particleboard. Other products that can be made from smaller, irregular stems and perhaps capitalize on unique physical characteristics such as fragrance and color offer additional opportunities. Detailed information relating to product yields, specifications, and manufacture is included in appendix D, tables 37 through 45.

### Solid Wood Products

Solid wood products include all products made of wood in its natural structural form. Wood may be used in very nearly the form in which it grows for posts, poles, fuelwood, and other round-wood products. More often the wood is sawed, sliced, chipped, or otherwise reduced and reconstructed in the desired form. Products such as lumber and ties require only cutting, while plywood, particleboard, and other laminated products additionally require reconstruction with adhesive to obtain the end product. Woodland species have been used sporadically for a variety of solid wood products, and have been investigated for others.

#### Sawn Products

The woodland species have not been widely utilized for sawn products because of their relatively small size and poor growth form. Pinyon railroad ties and mine timbers are produced by several small mills, however, principally for use in the mining industry (fig. 14).

Figure 14.--Pinyon railroad ties produced at a small New Mexico mill for use in the mining industry. Slabs from the logs are used to produce lump charcoal.

*Figure 15.--A deck of pinyon and juniper logs await processing at a small southwestern mill. The juniper is cut primarily on special order for furniture and novelty manufacturers.*

The ties are used untreated in open-pit rail lines that must be moved frequently. Mining firms report that the pinyon ties are much tougher and more resistant to breakage than ties made from other southwestern softwood species. They can be moved and reused a number of times.

Juniper species are also occasionally cut into lumber by smaller mills. The lumber is most often cut on special order for use in furniture and novelty items (fig. 15). Juniper book ends, lamp bases, small chests, and the like are popular southwestern novelty items (fig. 16). Products that can capitalize upon the unique characteristics of the species—fragrance, color, grain patterns—afford particular opportunities.

*Figure 16.--Novelty items made of juniper include (left to right) a kitchen cutting board, bookends, lamp, and bookholder. In the back are a wall plaque and table top, also of juniper. (Photo courtesy of Northern Arizona University School of Forestry.)*

### Veneer

Veneer is a thin layer or sheet of wood cut from the log by a lathe or slicer. Single layers of veneer may be used as decorative coverings over other materials. Several layers or plies of veneer are bonded together to form plywood. Eastern redcedar is a popular source of veneer for furniture, particularly cedar chests and similar products where color, figure, and fragrance are desired. The western junipers are physically similar to eastern redcedar in many respects, and therefore warrant consideration for similar uses.

In a Forest Service study, logs of Utah and alligator juniper were cut into rotary veneer at the Forest Products Laboratory (Englerth et al. 1953). A similar sample of logs was cut into sliced veneer by the Lane Company, Altavista, Virginia. The rotary-cut logs were preheated under water for 2 days to 160° F. Half the sliced logs were similarly heated to 180° F.; the other half were sliced cold.

Rotary veneer was cut in 1/16-inch and 1/32-inch thicknesses, with knife and nose-bar settings as follows (Englerth et al. 1953):

| Veneer thickness | Knife angle | Nose-bar opening: Horizontal | Nose-bar opening: Vertical |
|---|---|---|---|
| | (Deg.-min.) | (Inches) | |
| 1/16 inch | 90-10 | 0.055 | 0.016 |
| 1/32 inch | 90-35 | .028 | .012 |

Sliced veneer was cut 1/22-inch thick, at a speed of 28 strokes per minute. Heated logs cut well in both instances. Veneer from the cold logs sliced and dried poorly, and tended to warp and check.

The moisture content of the green veneer averaged 28 percent for heartwood and 124 percent for sapwood. Rotary-cut veneer was dried to 2-4 percent in a conventional veneer dryer, by the following drying schedules (Englerth et al. 1953):

| Veneer thickness and type | Dryer temperature (°F.) | Drying time (Min.) |
|---|---|---|
| 1/16 inch: | | |
| Sapwood | 250 | 15 |
| Heartwood | 250 | 10 |
| 1/32 inch: | | |
| Sapwood | 250 | 8 |
| Heartwood | 250 | 6 |

Sliced veneer was successfully kiln dried to 12 percent by eastern redcedar kiln schedules. Gluing and finishing tests indicated that the veneers could be glued and finished without difficulty by standard techniques.

The sample logs of both species contained numerous live and dead knots. Knots encased with bark, short grain around knots, and deep bark seams were also common in the logs. All of these characteristic features of the species, plus checking, splitting, and knotholes, constitute defects in the veneer (fig. 17).

The tests indicate that the two juniper species can be rotary cut or sliced satisfactorily. Cutting characteristics and surface quality compare favorably with eastern redcedar. The veneers were not considered adequate substitutes, however, primarily because eastern redcedar has a deeper, more striking color, and a more pronounced and lasting fragrance. The veneers should nevertheless be satisfactory for less demanding applications in furniture, paneling, and similar products.

### Particleboards

Particleboards are formed panel products consisting of wood particles bonded together with a synthetic resin or other binder. Wood particle types commonly used include chips, splinters, shavings, and flakes. Flakes are carefully manufactured, with specific thickness and length dimensions and grain direction. Other particle types result from chipping and/or hammermilling, and are somewhat random in shape and orientation. Particleboards may be manufactured as a single homogeneous layer or sheet, or as a multilayer sheet with different types of particles in core and face layers. They offer a distinct advantage in utilizing material too small, rough, or irregular to be useful for more conventional products. Desired physical characteristics can to some extent be "engineered" into particleboard.

The wood of practically any species can be used to manufacture particleboard, but the softwoods and low-density hardwoods are favored. A heavy wood such as Gambel oak is not well suited, although oak residues are used to a limited extent in splinter-type particleboards (Graham and Parrish 1961). Pinyon could provide excellent material for practically any type of particleboard, but cheaper ponderosa pine residues have the same general characteristics. The junipers appear to offer better opportunities for creating particleboards with distinctive qualities because of their specific gravity, texture, color, and fragrance (figs. 18, 19).

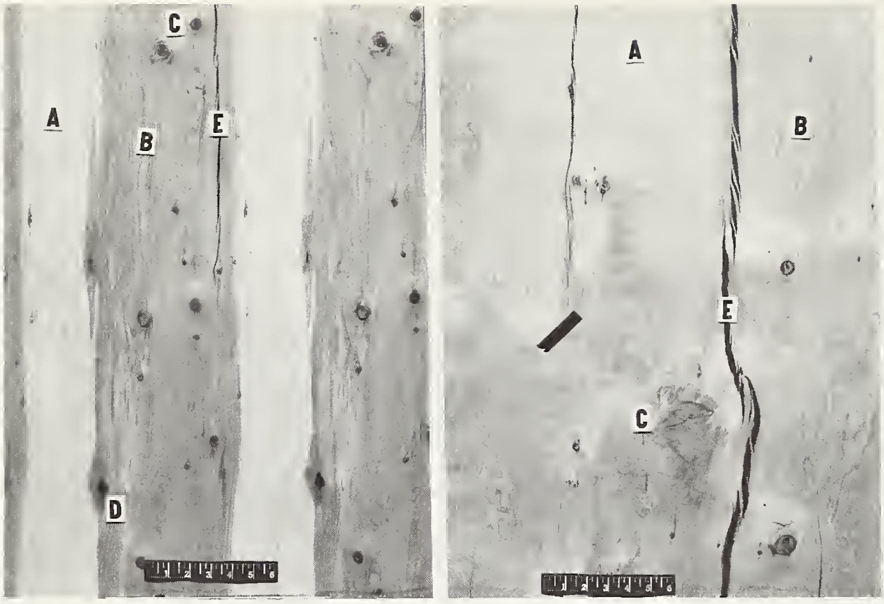



*Figure 17.--Rotary cut veneer from Utah (right) and alligator (left) juniper logs. Numerous knot, split, and check defects are evident.*

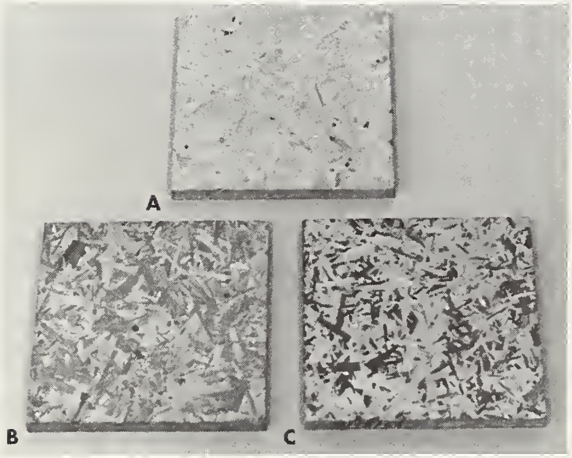



*Figure 18.--Samples of particleboard made from woodland species include:*

*A, Arizona cypress;*

*B, alligator juniper; and*

*C, Rocky Mountain juniper.*

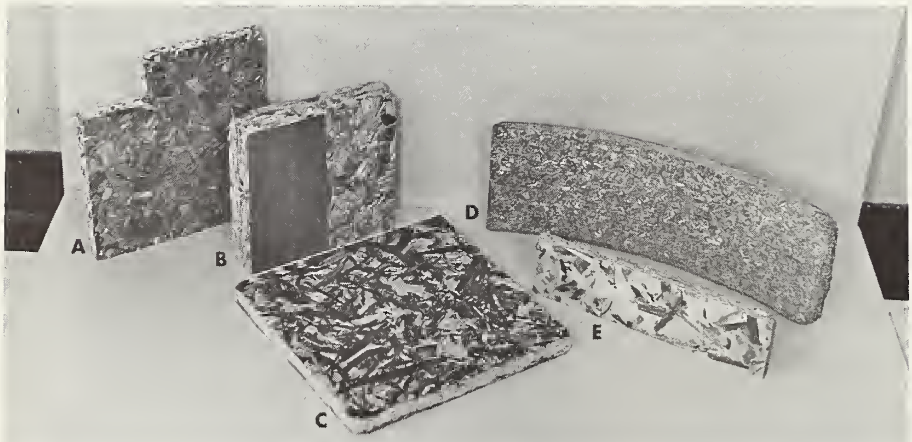



*Figure 19.--Particleboard products experimentally manufactured from juniper species include:*

*A, heavy acoustical particleboard;*
*B, acoustical particleboard with veneer overlay;*
*C, multilayer particleboard with faces of chipped entire trees, including bark, wood, and foliage;*
*D, molded curved seat back; and*
*E, conventional two-layer particleboard with juniper chip faces. (Photo courtesy of Northern Arizona University School of Forestry.)*

In limited tests at the Forest Products Laboratory (U. S. Forest Serv. 1966), alligator juniper and Rocky Mountain juniper bolts were converted to flakes 1 inch long, 0.015 inch thick, and random width. The flakes were bonded with 8 percent urea resin into single-layer medium-density particleboards. Strength and shrinkage characteristics of these boards are shown in table 5, with similar data for a comparable ponderosa pine board.

The tests indicate that satisfactory particleboard can be manufactured from these species. Linear dimensional movement (shrinkage) is rather high, especially for the alligator juniper boards, but this can largely be corrected through modification of the manufacturing process.

## Firewood

The woodland species have been utilized longer and more intensively for firewood than for any other product. As late as 1940, commercial sales of fuelwood in Albuquerque, New Mexico, were estimated to exceed 6,500 tons per year (Space 1940). In some rural localities wood is still the principal fuel used. The continued and growing popularity of wood-burning fireplaces also contributes to a steady urban demand. Commercial woodcutting and sale operations are usually an important source of income for a few individuals in each locality.

Heat content and ignition and burning characteristics are important basic wood fuel characteristics. Heat content may be most important in wood used as fuel, whereas ignition, flaming characteristics, fragrance, and other esthetic qualities may be more important in fireplace wood. Judged by these criteria, the woodland species make excellent firewoods.

Heat content is directly proportional to density. The gross heat content of a pound of ovendry wood is approximately 8,600 British thermal units (B.t.u.'s) for nonresinous species and 9,150 B.t.u's for resinous species (Reineke 1960). Net or usable heat per pound amounts to approximately 7,250 B.t.u's and 7,800 B.t.u's, respectively. Gross B.t.u. heat content per

**Table 5. — Strength and dimensional stability characteristics of particleboards made from selected southwestern species**

| Property | Unit of measure | Species | | | | Commercial standard requirements[2] |
|---|---|---|---|---|---|---|
| | | Alligator juniper | Rocky Mt. juniper | Ponderosa pine | Douglas-fir[1] | |
| Density | Lbs./cu.ft. | 40 | 40 | 35 | 40 | 37-50 |
| Moisture content at test | Percent | 7.4 | 7.3 | 8.4 | 8.6 | — |
| Strength: | | | | | | |
| Modulus of rupture | Lb./sq.in. | 3,430 | 4,180 | 3,720 | 4,020 | 1,600 |
| Modulus of elasticity | M lb./sq.in. | 272 | 367 | 460 | 570 | 250 |
| Perpendicular tension (internal bond) | Lb./sq.in. | 255 | 240 | 110 | 150 | 70 |
| Dimensional movement:[3] | | | | | | |
| Thickness movement | Index | 10.6 | 10.9 | 14.0 | 14.1 | — |
| Linear movement | Index | .88 | .49 | .23 | .23 | .35 |

[1]The Forest Products Laboratory uses a 40-pound Douglas-fir board as standard.

[2]Minimum property requirements for interior medium density, class 1 particleboard (U.S. Dep. Commerce 1966). Minimum property requirements for other types and classes of mat-formed particleboard are appended.

[3]Dimensional movement (shrinkage) indexes are based on differences between dimensions ovendry and at several levels of relative humidity, including soaked.

cubic foot for the four woodland species and ponderosa pine is:

| Species | Thousands of B.t.u./cu.ft. |
|---|---|
| Pinyon | 289 |
| Utah juniper | 274 |
| Alligator juniper | 243 |
| Gambel oak | 340 |
| Ponderosa pine | 238 |

Countryman (1967) found heat value per pound to be about 5 percent higher for heartwood than for sapwood in juniper. A similar relationship is likely to exist for other woodland species.

The wood of all four species ignites easily when dry, and burns well. Gambel oak and the junipers burn with little smoke and soot, and are therefore particularly favored for fuel in wood stoves. A tendency to throw sparks makes the junipers less desirable for use in open fireplaces. Pinyon is particularly favored as a fireplace wood. Because it is resinous, it ignites and burns more readily than the other woods, although with considerable smoke, and generates a distinctive incenselike fragrance.

Firewood is commonly measured and sold in standard cords, a stacked unit equivalent to 4 by 4 by 8 feet, or 128 cubic feet. Solid wood volume in a cord varies with size of wood and manner of stacking, but averages about 70 to 80 cubic feet per cord for stacked, short firewood. Occasionally, wood may be priced by weight. The weight of a cord of wood depends upon solid wood content, density of the wood, and moisture content. Average weight per standard cord for the woodland species is shown in table 6.

Table 6. — Average weight per standard cord[1] of firewood

| Species | Weight per standard cord | | |
|---|---|---|---|
| | Ovendry | Air-dry | Green |
| | Pounds | | |
| Pinyon | 2,528 | 2,831 | 4,171 |
| Utah juniper | 2,552 | 2,858 | 4,211 |
| Alligator juniper | 2,264 | 2,536 | 3,736 |
| Gambel oak | 3,168 | 3,548 | 5,227 |

[1] Calculated on the basis of 80 cubic feet of solid wood (stove or fireplace length) per standard cord, an average air-dry moisture content of 12 percent, and an average green moisture content of 65 percent.

Uncut mature pinyon-juniper stands often contain substantial number of standing dead trees. Howell (1940) found an average of 23 dead trees per acre in areas where past cutting had been minimized. These standing dead trees have been favored as sources of fuelwood, since the wood obtained is dry and ready for market (fig. 20). In many areas, however, firewood cutting has removed practically all

*Figure 20.--Standing dead pinyon and juniper trees are preferred fuelwood material. Pinyon and alligator juniper are especially favored.*

of the dead trees from the stand, and green material must be cut and held on a yard until dry enough to sell. Johnson and LeBaron (1967) found that green pinyon cut in 16-inch lengths dried from an initial moisture content of 65 percent to 25 percent or less in about 3 to 5 months of outdoor exposure. Split pinyon of the same length dried to the same level in about 3 to 5 weeks. Hardwoods such as Gambel oak may take as long as 9 months to 1 year to air dry (Nagle and Manthy 1966).

An abundant supply of green pinyon and juniper material is available to firewood operators. The wooded lands include Federal lands administered by the Forest Service, Bureau of Land Management, and Bureau of Indian Affairs; State lands; and large tracts of private rangeland. Stumpage costs for firewood cut from Federal lands is minimal, in the range of $0.50 to $1.00 per cord. Both live and dead firewood stumpage on National Forest land is usually priced at the Forest Service minimum of $0.50 per cord. Private landowners interviewed in a Utah study indicated that $0.50 per cord was sufficient stumpage for green pinyon and juniper, provided the slash was piled (Johnson 1965). Coordination with juniper and pinyon clearing programs on rangelands offers possibilities of avoiding stumpage costs altogether.

Gambel oak is generally available throughout the areas in which it occurs. More restrictive cutting practices are advocated, however, to leave sufficient live, vigorous trees to satisfy wildlife needs (McCulloch et al. 1965, Reynolds et al. 1970).

Firewood yields per acre vary with density, age, and composition of the stand. A Utah study reported average firewood yields of 4 to 6 cords per acre from pinyon-juniper stands (Johnson and LeBaron 1967). Howell (1940) found potential yields from pinyon-juniper woodlands in New Mexico and Arizona to vary from 0.8 to 24.8 cords per acre, with an average of 11.4. Stands in which pinyon was most abundant yielded the highest volumes. Appended tables describing tree, stand, stocking, and yield characteristics of the woodland species may be useful in estimating wood yields from particular stands.

Costs incurred in harvesting firewood include stumpage payments, costs of basic equipment such as chain saw and truck, and labor costs. Production rates vary substantially with stand density and composition. Areas yielding less than 2 cords per acre have been judged generally unsuitable for wood harvesting operations (Johnson and LeBaron 1967). Direct harvest costs per cord have been reported to range from approximately $6.25 to $8.25 (Johnson 1965, Sowles 1966). Total preparation costs per cord for green pinyon, including slash disposal, hauling to a reload or marshaling point, splitting, and piling, are reported by Johnson and LeBaron (1967) as follows:

| Labor cost/hour | Total cost/cord |
|---|---|
| $1.00 | $ 9.60 to $15.20 |
| 1.25 | 11.29 to 17.83 |
| 1.50 | 12.97 to 20.45 |

Transportation costs to major market areas can also be substantial.

The price received for firewood depends in part upon the distance it must be transported. In towns adjacent to wooded areas, pinyon and juniper wood retails for $20 to $25 per full cord. Oak sells for $5 to $10 more per cord. A study of the New Mexico market (Sowles 1966) found local wholesale buyers paying $14 to $18 per cord, and wholesalers in more distant communities paying $22 to $26 per cord. Delivered retail prices in towns 50 to 100 miles distant ranged from $25 to $36. Utah studies of potential markets for pinyon firewood have investigated average wholesale and retail prices in a number of large southwestern cities (table 7) (LeBaron and Johnson 1965, Johnson and LeBaron 1967, LeBaron 1968).

Estimated costs and returns for harvesting operations in five major market areas (table 8) indicate gross profit margins ranging from -$3 to over $30 per cord.

Experience in other regions indicates that a price change for firewood does not significantly affect the quantity used (Nagle and Manthy 1966). The southwestern market is probably similar in this respect, although higher prices will encourage consumers close to timbered areas to cut their own wood.

Most towns provide sizable local markets for firewood regardless of proximity to wooded areas. Larger urban areas distant from ready sources of wood are of course the better market areas. Sowles (1966) found that larger towns in western Texas would be particularly promising markets for New Mexico wood. Pinyon was especially favored by interviewed dealers.

Firewood is commonly produced and marketed haphazardly, with many small, independent operators working on an occasional or intermittent basis. Quality of the product, and quantity sold as a cord unit, are often questionable. The few commercial woodyards have considerable difficulty locating dependable sources of supply, and obtaining a product of reasonably consistent quality. Organized producers' cooperatives offer one possible means

Table 7. — Average wholesale and retail prices and estimated demand for pinyon fireplace logs in selected markets

| Market | Price per cord[1] | | Price per ton[2] | | Annual demand[3] |
|---|---|---|---|---|---|
| | Wholesale | Retail | Wholesale | Retail | |
| | Dollars | | | | Tons |
| Los Angeles | 30-36 | 44-50 | — | — | [4]57,600 |
| Denver | 25-30 | 35-47 | 21 | [5]35-37 | 2,000 |
| Albuquerque | 20-25 | 30-35 | 10-12 | 22 | 1,300 |
| Salt Lake City | 24-33 | [5]38-45 | 19 | [5]28-33 | 1,800 |
| Phoenix | 25-30 | [5]42-48 | 25-30 | [5]45 | [4]490 |
| Reno | 27-32 | 40-45 | 19-21 | 30 | 260 |

[1] Adapted from Johnson and LeBaron (1967).
[2] Adapted from LeBaron (1968)
[3] Adapted from LeBaron and Johnson (1965) and LeBaron (1968).
[4] Includes species other than pinyon.
[5] Price known to include delivery.

Table 8. — Costs and returns associated with the supply of pinyon fireplace wood to five markets (LeBaron 1967, 1968)

| Item | Salt Lake City | Ogden | Albuquerque | Denver | Phoenix |
|---|---|---|---|---|---|
| Harvesting area | Wayne Co. | Duchesne Co. | Socorro Co. | Saguache Co. | Gila Co. |
| Operation | 3 men, 2-T truck | 2 men, 1- and 2-T trucks | 4 men, 2-T truck | 6-7 men, 2-T and semitrucks | 2 men, 2-T truck and trailer |
| Gross receipts per load | $150.00 | $150.00 | $82.50 | $883.00 | $360.00 |
| Direct costs per load at: | | | | | |
| $1.00/hr. wage | 106.65 | 85.25 | 74.99 | 528.40 | 116.30 |
| 1.25/hr. wage | 117.90 | 95.75 | 86.24 | 592.90 | 131.30 |
| 1.50/hr. wage | 129.15 | 106.25 | 97.49 | 657.40 | 146.30 |
| Gross profit per cord at: | | | | | |
| $1.00/hr. wage | 10.08 | 15.06 | 1.75 | 14.43 | 34.81 |
| 1.25/hr. wage | 7.47 | 12.61 | -0.87 | 11.84 | 32.67 |
| 1.50/hr. wage | 4.85 | 10.17 | -3.49 | 9.21 | 30.52 |

of stabilizing supply, and developing and expanding marketing opportunities. Feasibility of a firewood cooperative has been investigated by the New Mexico State Forestry Department (Sowles 1966). The study points out that the factors essential to success of a cooperative are caliber of management, group or member cooperation, quality control, and marketing effort. The study suggests that either of two types of operation may work well:

1. A general producers' cooperative in which all members actively participate as producers or suppliers, with a general manager to attend to marketing, recordkeeping, and financial management.
2. A smaller group cooperative operating a concentration yard as a buying and marketing agency, much as a commercial woodyard operates.

Both the New Mexico and Utah studies emphasize the need to carefully evaluate alternative means of wood transport to the major market areas (LeBaron and Johnson 1965, Sowles 1966), since these charges often make up a large part of total delivered cost. Transportation costs by either truck or railroad are generally highest for small, irregular shipments. Negotiated rates, large-volume rates, and other transportation economies can often be obtained for larger, regularly scheduled shipments.

**Fenceposts**

Some of the woodland species have been utilized heavily for fenceposts for many years, especially the junipers because of their outstanding natural durability (fig. 21). Large numbers of posts were cut, both for local or personal use and as commercial enterprises, during the period of southwestern settlement and growth of the livestock and farming industries. Juniper posts have also been used as stub posts in powerline and telephone line construction, and as highway guardrail posts. In recent years, increased use of steel and preservative-treated pine and Douglas-fir has severely reduced the market for posts of woodland species. The total cut in a five-State area—Arizona, Utah, Nevada, Colorado, and New Mexico—is currently estimated to be 300,000 posts per year (LeBaron 1968).

Although the junipers are the most popular post species, Gambel oak has also been used extensively. The species commonly grows in clumps of small-diameter, reasonably straight trees, ideally suited to making posts. It is classified as decay resistant, and appears to be much more durable than other southwestern oaks (U. S. Forest Serv. 1967a). An investigation of old range fences showed that untreated Gambel oak posts outlasted both Emory and Arizona white oak (Long 1941), and should generally remain serviceable for 20 or more years.

Figure 21.--Despite increased use of steel and treated pine, peeled and unpeeled juniper fenceposts are still marketed in the Southwest.

Pinyon has not been favored for posts, since it is a nondurable wood and seldom achieves a growth form suitable for posts. Untreated pinyon posts seldom remain serviceable for more than 4 to 6 years.

The natural durability of the juniper species appears to be related to the presence of extractive compounds called tropolones, seven-membered carbon ring compounds with properties similar to the phenols (Gardner 1962). Four tropolones, $\beta$-thujaplicin, nootkatin, dolabrin, and pygmaein, are present to some degree in southwestern junipers. The tropolones which occur only in the heartwood, are concentrated in the outer heartwood, with only traces near the pith.

In early studies (Arizona Highway Dep. 1940, Meagher 1940, U. S. Forest Serv. 1941a) juniper posts in existing fences of known age were studied to determine influence of size, heartwood, and soil moisture upon service life. Post durability was strongly dependent upon proportion of heartwood present (fig. 22), and to a lesser extent upon soil moisture or climatic zone (fig. 23). The sapwood of all juniper species decayed in 5 to 15 years, but the heartwood rarely showed signs of decay regardless of age. No significant differences were noted between juniper species.

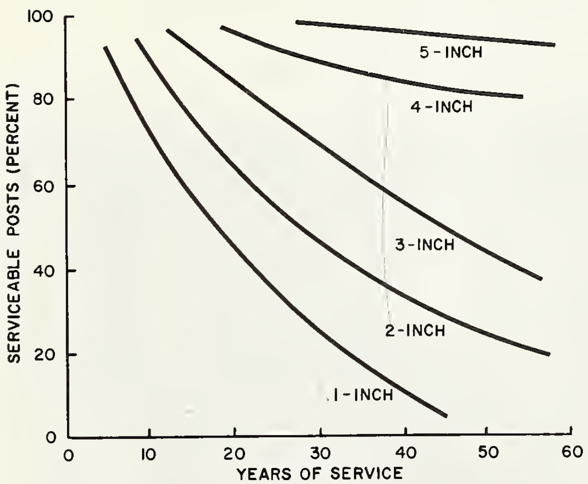



*Figure 22.--Service life of juniper posts is largely dependent upon the proportion or size of heartwood present. Illustrated is the average service life of posts with heartwood diameters varying from 1 to 5 inches. (Adapted from Meagher 1940.)*

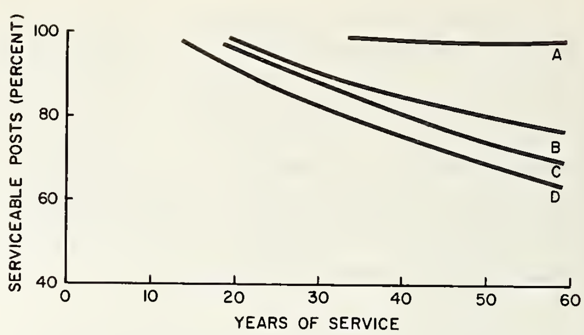



*Figure 23.--Service life of juniper posts is also affected by soil moisture conditions associated with the broad climatic zones: A, desert; B, woodland; C, conifer or pine; D, irrigated lands. (Adapted from Meagher 1940.)*

Minimum specifications for juniper posts, developed by Meagher (1940), are based on a minimum serviceability of 80 percent after 40 years of service (table 9). Heartwood diameter was considered the major limiting criterion.

A series of test fences were installed in Arizona and New Mexico in 1939-40 by the U. S. Forest Service to further investigate service life of posts of southwestern species (Meagher 1939, 1951). Fourteen native species

**Table 9. — Minimum suggested heartwood diameter in round juniper posts[1] (Meagher 1940)**

| Climatic zone | Minimum heartwood diameter | |
|---|---|---|
| | At ground line | At butt |
| | Inches | |
| Desert zone (high temperature, low moisture) | 3.0 | 3.5 |
| Woodland zone (intermediate temperature and moisture) | 3.5 | 4.0 |
| Sawtimber zone (low temperature, high moisture) | 4.0 | 4.5 |
| Irrigated lands (high temperature and moisture) | 4.0 | 4.5 |

Minimum specifications are those considered necessary to insure 80 percent serviceability 40 years after installation.

are represented in the fences, including the junipers, pinyon, and Gambel oak. The fences have been reexamined periodically, most recently in 1965. The performance of untreated posts in the fences generally substantiates the results of earlier studies (appendix D, table 39). The junipers are extremely durable, and Gambel oak is more durable than other oaks. The study indicates, however, that untreated Gambel oak deteriorates rather rapidly after about 15 years of service, with a maximum service life of approximately 20 years.

Harvesting fenceposts in woodland stands is a highly selective operation, since only stems meeting specified physical requirements can be utilized. Stems must be relatively small, slender, and straight. Young and intermediate age stands offer the best opportunity. Where juniper stands have been selectively cut or "high graded" for posts over the years, suitable post stands are no longer available. Utah and one-seed junipers have been favored because of their smaller size and frequent multiple stems. Alligator juniper is also frequently used, principally by splitting the larger stems into a number of posts. Split posts are generally superior to round posts, since there is less sapwood in contact with the soil, and less chance for the post to become loose as the sapwood rots.

Post yields vary widely with the age and species composition of the stand, and with the past history of cutting in the stand. Howell (1941) estimated yields to average 46 posts per acre in uncut pinyon-juniper woodlands in Arizona and New Mexico. Reveal (1944) has estimated an average of 1 to 2.4 fenceposts per tree in Utah juniper trees with primary stems 6 inches and over in d.b.h.

Commercial post cutting and selling is primarily a part-time or fill-in job for individuals involved in farming, ranching, trucking, or similar occupations. A few larger post and pole or wood yards attempt to stock and sell posts year-round. Cutting is limited almost entirely to the junipers. Stumpage costs for juniper posts cut from Federal lands range from the Forest Service minimum of $.08 per post on National Forest lands to $.10 to $.15 per post reported for Bureau of Land Management lands in Utah (LeBaron 1968). A few operators may buy large stumpage permits and hire cutters on a piece-rate basis. More often, however, cutters operate independently, and sell small quantities of posts to local concentration yards or users. Prices paid for cut posts depend partly upon prevailing wage rates in alternative employment, but seldom exceed a wage equivalent of $1.00 - $1.50 per hour. Prices received by cutters, wholesalers, and retailers in Utah are reported by LeBaron (1968) to average:

| Transaction | Cost or price/post |
|---|---|
| Piece rate for hired cutters | $0.20 to $0.25 |
| Wholesale yard purchase from independent cutters | 0.30 to 0.35 |
| Wholesale sales to truckers or retailers | 0.40 to 0.45 |
| Sales direct from cutter to local user | 0.50 to 0.70 |
| Commercial retail sales | 0.85 |

## Chemical Products

Chemical products include (1) products made by chemically treating or altering wood fiber, and (2) products derived from the chemical constituents or extractives in the wood. Pulp, paper, and related products such as fiberboard are among the best known chemical products in the first category. Charcoal manufacture through carbonization is another example of chemical alteration of the wood to obtain a product. A variety of chemicals including turpentine, rosin, and various oils can be obtained through wood or foliage distillation and solvent extraction processes, or through processing oleoresins collected from living trees.

Chemical utilization offers particular advantages for the woodland species, since stem size and form are not critical.

### Charcoal

Charcoal is produced by heating wood in airtight ovens or chambers that exclude oxygen, or by burning the wood under kiln conditions that limit the amount of oxygen available for combustion. In a typical kiln operation, the wood is ignited and partially burned. The heat generated dries the wood and raises temperatures to the coaling or carbonization point. Thereafter oxygen intake is systematically reduced to allow only enough combustion to generate the heat required to continue carbonization. Water, extractives, and other volatiles escape as gases, leaving most of the carbon as charcoal.

Masonry and sheet metal kilns are commonly used to batch produce charcoal from cordwood or larger wood residues. Masonry block kilns of approximately 2- to 10-cord capacity have proved particularly economical and efficient

for the smaller producers (fig. 24)(U. S. Forest Serv. 1957, 1961). More recently, improved methods have been developed for continuously carbonizing chipped material and fine mill residues. These methods include both vertical and horizontal tubes, chambers, or retorts, through which fine wood material is force fed. Most of these continuous processes use external gas or oil burners for initial heating, and burn recycled wood gases to maintain carbonization temperatures.

Larger plants equipped with externally heated ovens or retorts may be further equipped to recover chemical byproducts. Primary chemicals recovered from processing hardwood are acetic acid and methanol, but these chemicals are now being produced more cheaply synthetically. Byproduct recovery from softwoods has been limited to retort carbonization of resinous pine stumpwood, from which pine tar and solvent oils are obtained (U. S. Forest Serv. 1961). The recovery of liquid byproducts from kiln operations is physically impractical, since they are partially consumed by combustion in the kiln and recoverable quantities would be small.

Charcoal produced from cordwood or larger residues of the heavier woods may be sold and used in natural lump form. Charcoal from lighter woods and from fine material, however, must be briquetted to meet the requirements for most uses. Much of the charcoal from heavier woods is also briquetted, since briquettes have a market advantage. Briquettes are made by pulverizing charcoal, adding water and a starch binder, and roll pressing the mixture into the desired size and shape. Briquettes are molded at pressures of 3,000 to 4,000 pounds per square inch, resulting in a briquette specific gravity of approximately 0.70. Briquetting equipment and plant facilities represent a large additional capital investment; consequently, briquetting is commonly restricted to larger, high-capacity plants. Smaller charcoal producers often sell their product to such a larger firm.

All of the woodland species are suitable raw material for charcoal. All wood is about 50 percent carbon; consequently, charcoal yields from various species will be proportional to the density of wood. Denser species are preferred, since charcoal yield per unit of wood volume will be greater.

Gambel oak is especially well suited to the production of lump charcoal since it is a heavy wood and will produce a correspondingly heavy lump product. Lump charcoal produced from mesquite, a wood similar in density to Gambel oak, has been successfully marketed in the Southwest for several years. Although lighter woods such as the junipers and pinyon will produce a lighter, less desirable lump product, pinyon charcoal was used extensively as a

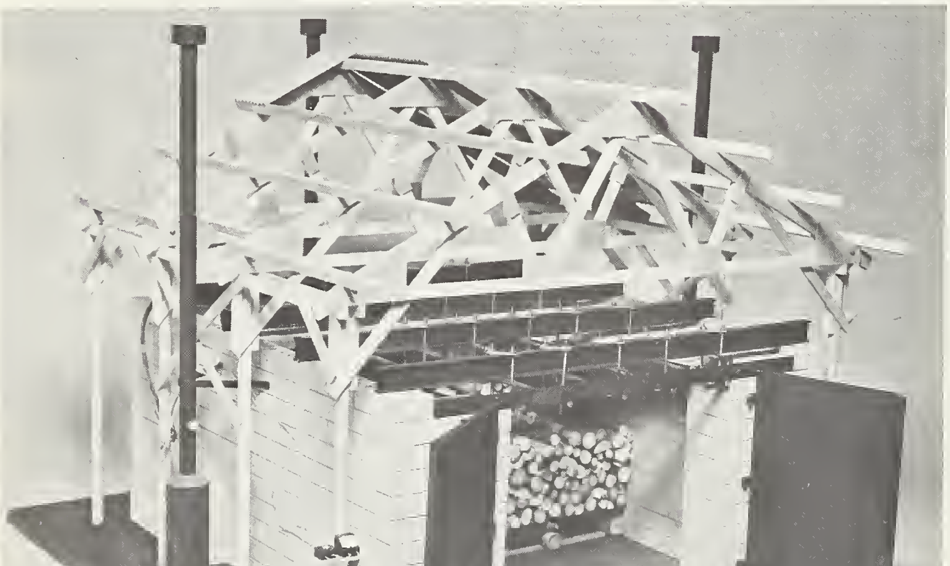


*Figure 24.--Scale model of a 7-cord masonry block kiln.*

smelter fuel in early mining operations in the Southwest. An account of early woodland utilization in New Mexico describes charcoal production in beehive-type brick kilns with capacities of 60 cords each (Space 1940).

Yields of charcoal depend upon the efficiency of the converting equipment and process used. Well-made charcoal will contain approximately one-half the volume and one-third the dry weight of the wood from which it is made (U. S. Forest Serv. 1961). The average conversion value is about 32 percent (table 10). Lower yields indicate that the kiln or the operating procedure could be improved. Higher yields probably indicate a greater amount of retained volatiles and consequent reduction in quality.

Yields of charcoal per kiln charge or per cord will also vary with wood size, form, and moisture content. Small, crooked, excessively tapered wood will contain much less solid wood per cord or charge than larger, straighter wood. To obtain proper coaling, however, stick diameters should not exceed about 10 inches (U. S. Forest Serv. 1957). Larger sticks may be split. Large quantities of bark should be avoided. Although bark will yield approximately the same proportion of charcoal by weight as does wood, the charcoal will be lighter, break more easily, and produce more fines. Wood at moisture contents of 20 to 40 percent is preferable (U. S. Forest Serv. 1957). At lower moisture levels, the wood may coal too fast and develop excessive kiln temperatures. Wetter wood may require additional fuel for satisfactory ignition, and will require a longer coaling period.

Yields of 36 percent from Utah juniper and 34 percent from pinyon were obtained in a sheet metal kiln in Utah (Johnson 1965). Johnson suggested air drying green wood to a moisture content of approximately 30 percent, and reducing pieces larger than 10 inches in diameter to short lengths. An average charcoal yield of about 30 percent was obtained with a block kiln in a limited study of charcoal production from pinyon and juniper in Colorado (Troxell and Johnson 1964). This study concluded that, for maximum yields and operational efficiency, wood bolts should be not larger than 8 inches in diameter, and should have a moisture content of about 30 percent. The bark on Utah juniper was found to act as an effective kindling for igniting the charge.

Good quality charcoal has a heat content of about 13,000 B.t.u.'s per pound, and burns cleanly with little smoke or ash (U. S. Forest Serv. 1961). The chemical properties of charcoal are the most important indicators of quality (table 11). Properties of particular interest include moisture content, fixed carbon content, and content of volatiles and ash. Volatile content greater than about 24 percent will cause undesirable smoking when the charcoal is burned. Less than about 18 percent volatiles may make ignition difficult and burning slower.

**Table 10. — Calculated charcoal yields per cord from selected woodland species[1]**

| Species | Specific gravity | Wood dry weight: Per cubic foot | Wood dry weight: Per cord | Charcoal recovery per cord[2] | Wood per ton of charcoal |
|---|---|---|---|---|---|
| | | Pounds | Pounds | Pounds | Cords |
| Pinyon | 0.506 | 31.6 | 2,212 | 708 | 2.82 |
| Utah juniper | .511 | 31.9 | 2,233 | 715 | 2.80 |
| Alligator juniper | .453 | 28.3 | 1,981 | 634 | 3.15 |
| Gambel oak | .634 | 39.6 | 2,772 | 887 | 2.25 |
| Mesquite[3] | .700 | 43.7 | 3,059 | 979 | 2.04 |
| Mixed oak and hickory[3] | .650 | 40.6 | 2,842 | 909 | 2.20 |

[1]Based upon an average solid wood content of 70 cubic feet per cord for stacked 2-foot wood.
[2]Based on an average recovery factor of 0.32 for conventional kiln operations (U.S. Forest Serv. 1961).
[3]Included for comparative purposes.

Table 11. — Physical and chemical properties of lump charcoal produced from selected woodland species

| Species | Specific gravity | Weight per cubic foot | Chemical analysis: Moisture content | Fixed carbon | Volatiles | Ash |
|---|---|---|---|---|---|---|
| | | Pounds | Percent | | | |
| Pinyon[1] | 0.31 | 19.3 | 1.42 | 84.76 | 14.15 | 1.18 |
| Utah juniper | | | | | | |
| Arizona | .32 | 20.0 | 4.21 | 78.52 | 20.62 | .86 |
| Utah[1] | .27 | 16.8 | 1.45 | 82.79 | 16.24 | .97 |
| Alligator juniper | .29 | 18.1 | 5.54 | 72.41 | 27.62 | .56 |
| Gambel oak | .41 | 25.6 | -- | -- | -- | -- |
| Mesquite[2] | .41 | 25.6 | 1.41 | 82.42 | 10.18 | 7.40 |
| Desirable range[3] | | | 2-4 | 74-81 | 18-23 | 1-4 |

[1] Adapted from Johnson (1965).
[2] Adapted from Kotok (1955).
[3] U.S. Forest Serv. (1961).

Additional properties important in lump charcoal are its density and its resistance to breakage and crumbling.

Optimum coaling temperature for good quality charcoal is approximately 850° - 950° F. (U.S. Forest Serv. 1961). Excessively rapid coaling at higher temperatures may result in low volatile content, and may produce charcoal that is easily crushed. Higher temperatures also produce more fixed carbon, but reduce charcoal yield.

Charcoal production costs will vary extensively with type of equipment used, capacity, species of wood, proximity to wood source, and local labor costs. Some minimum level of production is necessary for any operation to be economically feasible. A weekly production of 7 to 10 tons has been suggested as the minimum production level for a full-time operation (Johnson 1965, Kotok 1955). Charcoal from woodland species will generally be produced in either sheet metal or masonry block kilns. Estimated costs of producing pinyon and juniper charcoal in portable sheet metal kilns in Utah (Johnson 1965), and mesquite charcoal in block kilns in Arizona (Kotok 1955) are itemized in table 12.

One New Mexico operator who produces, bags, and sells lump charcoal achieves unusual economies in kiln construction and maintenance (fig. 25). A long trench 10 to 12 feet deep is cut in the ground, and bays excavated at right angles to the main trench are roofed and walled across the front to create kilns. Heavy pinyon slabs remaining from railroad tie manufacture are the primary material used for charcoal. Most of the briquetted charcoal produced, as well as some in lump form, is used by the rapidly expanding outdoor and restaurant barbeque market. Substantial quantities of bulk charcoal are used in various metallurgical and chemical processes. Large quantities are also used in tobacco curing, water purification, and poultry and animal feeds (appendix D, table 42). Demand for charcoal in Arizona and adjoining States was estimated in 1964 to be (LeBaron 1968):

| State | Charcoal demand (Tons) |
|---|---|
| Arizona | 3,560 |
| New Mexico | 1,615 |
| Colorado | 4,600 |
| Utah | 2,000 |
| Nevada | 900 |
| | 12,675 |

Table 12. — Estimated production costs per ton of lump charcoal produced in sheet metal and masonry block kilns[1]

| Production cost item | Estimated cost range | |
|---|---|---|
| | Sheet metal kilns [2] | Masonry block kilns[3] |
| Seasoned wood at kiln site | $19.65-26.25 | $13.50-27.00 |
| Wood preparation (buck, sort, etc.) | 1.00- 2.00 | .50- 1.50 |
| Loading kiln | 2.50- 3.75 | 1.00- 3.00 |
| Tending kiln | 1.25- 1.25 | -- |
| Unloading kiln | 3.75- 5.00 | 2.00- 4.00 |
| Water | -- | .50- 1.00 |
| Sacking in 10-lb. bags | 12.00-15.00 | 6.00-11.00 |
| Bags | 6.00- 7.00 | 10.00-13.00 |
| Depreciation | 4.00- 8.00 | 5.00- 7.00 |
| Hauling to warehouse | 2.00- 3.00 | 1.00- 3.00 |
| Warehousing | 3.00- 5.00 | 2.00- 5.00 |
| Miscellaneous (taxes, insurance, supervision) | 2.00- 4.00 | (4) |
| Total cost per ton | 57.15-80.25 | 41.50-75.50 |

[1]Estimated investment costs associated with charcoal production in sheet metal and block kilns are shown in appendix D, table 40.

[2]Estimated costs for the production of pinyon and juniper charcoal (Johnson 1965).

[3]Estimated costs for the production of mesquite charcoal (Kotok 1955). The costs shown are based on 1955 monetary values.

[4]Included with other items.

Figure 25.--Pinyon lump charcoal is produced at this New Mexico plant in dug-out kilns extending laterally from the main access trench. Chimneys are in place on bays or kilns in which a charge is being processed.

Prices obtained for charcoal depend upon the form in which it is marketed. The market price for bulk charcoal delivered to a briquetting plant is approximately $35 to $50 per ton. The Utah study found briquetters paying $43 to $48 per ton for pinyon and juniper lump charcoal.

Average bulk prices reported for unscreened lump charcoal in 1961 were (U.S. Forest Serv. 1963):

| **Region** | **Price per ton** |
|---|---|
| Northeast | $64 |
| Southeast | 32 |
| Lake States | 40 |
| Central States | 33 |
| Southern | 33 |
| California | 46 |

Screened lump charcoal averaged about $15 per ton higher than unscreened. Bagged or packaged lump charcoal may wholesale for $75 to $110 per ton (Johnson 1965). In comparison, well-organized sales operations can obtain wholesale prices of $85 to $120 per ton for packaged briquettes. Average retail markup is about $30 per ton.

Smaller producers should generally avoid the bulk markets, and concentrate upon packaging a product for wholesale-retail trade. The lighter lump charcoals produced from juniper and pinyon may be at some disadvantage in the retail market, although the Utah study of charcoal potential for these species concluded that the best opportunities lie in producing, bagging, and selling lump charcoal (Johnson 1965, LeBaron 1968). This conclusion was based upon the apparent lack of competition among producers of bagged lump charcoal, higher profit-to-cost ratios, and the assumption that consumers will recognize some inherent advantages in lump charcoal. The same study points out the disadvantages of small producers selling lump charcoal to briquetting plants. These plants usually incorporate their own charcoal production facilities, and buy outside charcoal only at marginal prices.

**Pulping**

Pulping offers an opportunity for utilizing large volumes of wood fiber from woodland species, particularly the softwoods. Pulp, paper, and related products comprise one of the most rapidly expanding sectors of the wood utilization industry. Continued growth, and with it the need for a wider resource base, seems assured. Exceptionally large or well-formed trees are not required to produce pulpwood, although extreme stem deformities should be avoided. Recent trends toward mechanized harvesting systems and chipping in the woods may provide improved means of handling irregular material and relatively small volumes per acre.

Pinyon-juniper stands offer the best opportunity for pulpwood production, since they contain substantial volumes of suitable material and occupy large, continuous areas. The growth form and debarking characteristics of pinyon are particularly adaptable to pulpwood processing. Although hardwoods can be used for pulp, the oaks are difficult to pulp and require special processing techniques. In addition, softwoods yield longer fibers than hardwoods, and are favored for most types of paper.

Properties of wood that affect quality for pulp include density, cellulose content, fiber length, proportion of heartwood and extractives, and presence of abnormalities such as compression wood and decay. The denser woods yield more pulp per unit volume of solid wood processed. Both pinyon and the junipers are relatively dense compared to other western softwoods, averaging from 10 to 20 percent heavier than ponderosa pine.

Yields of chemical pulp also depend on the chemical composition of the wood. Chemical pulping processes dissolve the lignin fraction, and pulp yields are proportional to cellulose content. The chemical composition of wood cell wall material is relatively uniform among species within the softwood and hardwood groups. Major chemical constituents of softwoods (including pinyon and juniper) and hardwoods (including Gambel oak) are (Locke 1961):

| **Chemical fraction** | **Softwoods** (Percent) | **Hardwoods** |
|---|---|---|
| Cellulose | 42 | 45 |
| Hemicellulose | 25 | 25 |
| Lignin | 30 | 23 |

Yields of pulp from either mechanical or chemical pulping processes can be estimated from specific gravity and average pulp recovery factors (table 13). Specific gravity of extracted wood provides the most accurate estimate of yield.

Fiber length influences the strength and other mechanical properties of pulp. Longer fibers develop stronger pulp and are preferred for most kinds of paper. Pinyon has an average fiber length of 2.00 mm, compared to average fiber lengths of 3.60 mm for ponderosa pine and 1.00 to 1.50 mm for the oaks (U. S.

Table 13. — Calculated pulp yields from mechanical and chemical processing of selected softwood woodland species[1]

| Species | Extracted specific gravity | Extracted density | Estimated pulp yield: Per cubic foot, Mechanical | Per cubic foot, Chemical | Per cord[2], Mechanical | Per cord[2], Chemical |
|---|---|---|---|---|---|---|
| | | Lb./cu. ft. | Pounds | | | |
| Pinyon | 0.484 | 30.2 | 28.7 | 13.6 | 2,009 | 952 |
| Utah juniper | .466 | 29.1 | 27.6 | 13.1 | 1,932 | 917 |
| Alligator juniper | .426 | 26.6 | 25.3 | 12.0 | 1,771 | 840 |

[1] Yields calculated on the basis of (a) groundwood mechanical recovery factor of 95 percent; (b) sulfate chemical recovery factor of 45 percent for unbleached kraft pulp.
[2] Calculated on the basis of 70 cubic feet of solid wood per cord. Stem form and size will affect solid wood content per cord.

Forest Serv. 1964). In a recent study at Northern Arizona University, Hart (1966) found that pinyon fibers produced during the first few decades are shorter than those produced later in the life of the tree. Average fiber length for pinyon wood developed after 40 years of age was about 2.00 mm, ranging from 1.8 ± 0.12 mm at 50 years to 2.3 ± 0.25 mm at 180 years.

Chemical extractives in wood do not contribute to pulp yields, and can reduce brightness. The heartwood of most species contains far more resins, gums, and other extractives than does the sapwood; consequently, high proportions of heartwood produce lower pulp yields and higher tall oil yields. Since both pinyon and juniper have high proportions of heartwood with relatively high extractive content, some adverse effect upon pulp yield and brightness can be expected.

Compression wood is an abnormal cellular structure formed on the lower sides of leaning trunks and the branches of conifers. The cells or fibers are shorter than normal cells, and have a lower cellulose content (Westing 1965). Compression wood does not seriously affect ground-wood yield, but does significantly reduce yields of chemical pulp. The shorter fiber also reduces pulp strength, and the pulp produced is more difficult to bleach. Because juniper trees often lean and have distorted stems, they contain large amounts of compression wood which could limit use of the species for chemical pulp. Pinyon would not be expected to contain unusual amounts of compression wood in the trunk, but if the typically numerous large limbs are included as pulpwood, the aggregate compression wood content is also likely to be high.

Decayed wood usually affects pulp strength and brightness. Rots that attack principally cellulose will also reduce yields. Decay is rare in the juniper species, however, and infrequent in pinyon.

Dead standing timber can be used to produce acceptable pulp, although freshly cut or green wood is preferred. Dead material is less desirable for pulp because of the lower moisture content and frequent occurrence of stains and decay. Moisture content affects grinding or chipping characteristics and pulp properties (Schafer 1961). Drier wood yields shorter fibers than does green wood, and produces pulps with poorer strength properties.

The U. S. Forest Products Laboratory evaluated the physical and chemical properties of alligator juniper wood (table 14), its sulfate pulping characteristics, and properties of the sulfate pulp (Martin 1961). The chemical properties indicate a relatively high lignin content, low pentosan content, and high extractive content, all of which are generally detrimental to pulp yield and quality.

The material pulped satisfactorily, but produced low yields of pulp that required approximately twice the quantity of bleach chemical commonly required for bleachable pulps. The

Table 14. —Physical and chemical properties of alligator juniper pulpwood (adapted from Martin 1961)

| Property | Unit of measure | Observed value |
|---|---|---|
| Physical:[1] | | |
| Rate of growth | Rings/inch | 25.10 |
| Specific gravity[2] | -- | .47 |
| Density | Lb./cu. ft. | 29.30 |
| Heartwood volume | Percent | 61.00 |
| Chemical:[3] | | |
| Lignin | Percent | 34.40 |
| Holocellulose | Percent | 57.40 |
| Alpha-cellulose | Percent | 39.70 |
| Pentosans | Percent | 4.50 |
| Ash | Percent | .30 |
| Solubility in: | | |
| Alcohol-benzene | Percent | 6.60 |
| Ether | Percent | 2.20 |
| 1% sodium hydroxide | Percent | 16.10 |
| Hot water | Percent | 3.30 |

[1]Based on disks cut from six sections of split logs that averaged 11.5 inches in diameter.
[2]Based on ovendry weight and green volume.
[3]Based on a sample of chips used for pulping; all percentages based on ovendry wood.

strength of the pulp was intermediate between that of typical hardwood and softwood sulfate pulps. The pulp was judged too difficult to bleach for white paper stock, too weak for unbleached high-grade bag and wrapping papers, and too soft for corrugating board medium. The study report suggests that juniper sulfate pulp may be of greatest value in mixtures or blends with other softwood pulps (Martin 1961).

Pinyon has been experimentally pulped by a commercial pulp mill, with satisfactory results. The extractive content of the wood, and tall oil yield in the pulping process, was reported to be less than that for ponderosa pine. Brightness and bleaching characteristics would be expected to be similar to those of ponderosa pine. Because of the shorter fiber length, however, pulp strength characteristics would probably be below the average for softwood pulps.

### Extractive-based products

Extraneous chemicals called extractives, which include such substances as resins, oils, and tannins, occur in the wood of most tree species. Extractives account for many of the specific characteristics that distinguish one wood from another—color, fragrance, decay resistance—and help determine potential uses of the wood. All four of the woodland species contain appreciable quantities of extractives. Extractions of increment core samples provide a measure of total extractives soluble in ethyl alcohol-benzene and hot water:

| Species | Percent extractives |
|---|---|
| Pinyon | 4.3 |
| Utah juniper | 8.8 |
| Alligator juniper | 6.0 |
| Gambel oak | 10.6 |

Wood extractives occur largely within cell cavities and specialized intercellular structures such as resin ducts. Some extractives are obtained directly from the sap or gum of living trees; others are obtained from chipped or shredded wood by solvent or steam distillation. A number of the chemical components of wood extractives are commercially valuable; for example, the nationally important naval stores industry is based on extractive products obtained from pine resin. Additional extractives of potential industrial importance occur in the foliage of some trees, including the junipers.

**Pinyon.**—Pinyon trees contain significant quantities of oleoresin or gum, and will bleed readily when wounded (fig. 26). The resin can be collected by tapping living trees in the same manner that southern pine species are "worked" for gum. The potential value of extractive products depends on the yield of oleoresin, and its physical and chemical properties.

An extensive study of the feasibility of collecting resin from pinyon trees was conducted by Deaver and Haskell (1955) on the Navajo and Hopi Indian Reservations. Selected sample trees 6 inches or more in diameter representing a variety of stand conditions and geographic locations were "chipped" by cutting broad V-notches one-half to three-fourths inch deep above a metal gutter and can (fig. 27). Periodically, another streak or notch was added above the previous streaks. Resin was collected from the cans at 2-week intervals during the growing season.

Figure 26.--Pinyon trees bleed resin readily when wounded.

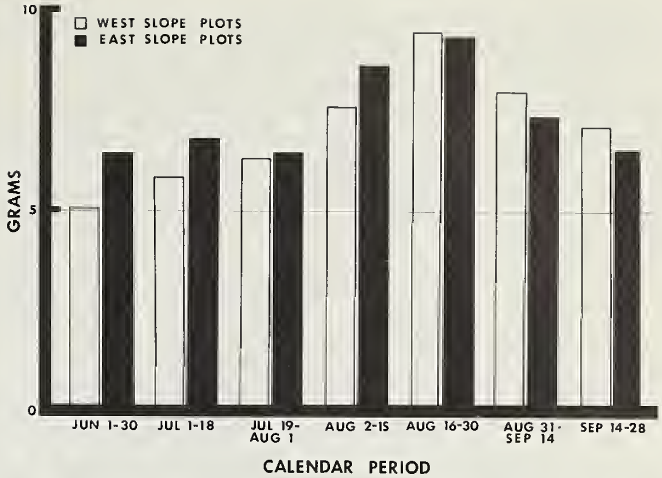



Figure 28.--Average daily resin yield per tree from chipped pinyon trees. (Adapted from Deaver and Haskell 1955.)

Resin yield was low and extremely variable between trees. Over 27 percent of the sample trees were abandoned because of extremely poor resin yields—less than 10 grams in a 2-week collection period. Average daily yields on sample plots ranged from 5.1 to 9.3 grams per productive tree, depending upon time of season and location of plot (fig. 28). Resin yield per productive tree averaged approximately 650 grams (1.4 pounds) for the 4-month season, June through September. By comparison, 10-inch-diameter southern pines will produce 7 to 10 pounds of gum per year (U. S. Dep. Agr. 1935).

Some variation in resin production appeared to be associated with tree size, vigor, elevation of the plot, and geographic aspect. Average yield decreased with increase in elevation, and was poorer on west aspect plots. Smaller trees were in general poorer producers; most of the extremely low producers were 7 inches or less in diameter.

Deaver and Haskell (1955) concluded that chipping would be feasible only in stands with at least 20 to 25 pinyon trees per acre 6 inches or more in diameter. Economic opportunities

Figure 27.--To "chip" a pinyon tree for resin production, V-shaped notches are cut above a metal gutter and cup. The notches are cut singly at intervals of from one to several weeks during the time the tree is worked. (Adapted from Deaver and Haskell 1955.)

could be improved by refining collection methods and applying techniques to increase resin yields.

The properties of pinyon gum largely determine its potential uses. Resin collected during the Arizona study contained 20 percent volatile constituents or gum turpentine and 80 percent rosin (Deaver and Haskell 1955). Gross chemical and physical characteristics of the turpentine fraction included:

| | | |
|---|---|---|
| d-$\alpha$-pinene content | | 70-75 percent |
| $\beta$-pinene content | | 5 percent |
| d-cadinene content | | 15-20 percent |
| Density | $d^{25}$ | 0.868 |
| Index of refraction | $n^{25}_{d}$ | 1.4708 |

Important physical characteristics of the rosin fraction were:

| | |
|---|---|
| Acid value | 156 |
| Softening point (°C) | 73° - 74° |
| Saponification No. | 166 |

Results of an earlier analysis by the National Paint, Varnish, and Lacquer Association (Westgate 1943) agree closely with an acid value of 156, saponification number of 164, and melting range of 78° - 87° C.

In an intensive study of the turpentine fraction, oleoresin samples from common pinyon yielded 24 percent turpentine with the following physical characteristics (Mirov 1961):

| | | |
|---|---|---|
| Density | $d^{22}_{4}$ | 0.8708 |
| Index of refraction | $n^{22}_{d}$ | 1.4728 |
| Specific rotation | $\alpha^{22}_{578}$ | +17.9° |

The chemical composition of the turpentine was:

| Chemical compound | Percent |
|---|---|
| d,dl-$\alpha$-pinene | 46 |
| Unidentified terpenes | 1 |
| $\beta$-myrcene | 2 |
| d-$\Delta^3$-carene | 6 |
| dl-limonene | 1 |
| Terpinolene | 1 |
| Ethyl caprylate | 6 |
| Unidentified oxygenated compounds and hydrocarbons | 12 |
| Sesquiterpenes related to cadinene | 16 |
| Residue and loss | 9 |
| Total | 100 |

The distinctive fragrance of pinyon is due primarily to the presence of ethyl caprylate, which is not known to exist in the turpentine of any other pine species.

An analysis of the rosin fraction indicated that pinyon rosin is unique in containing a high proportion of $\Delta^8$-isopimaric acid (Joye and Lawrence 1967); other pine species typically have little or none. The resin acid composition of pinyon rosin was:

| Resin acid | Percent in acid fraction |
|---|---|
| $\Delta^8$-Isopimaric | 55.0 |
| Abietic | 21.0 |
| Isopimaric | 5.7 |
| Neoabietic | 5.4 |
| Levopimaric and Palustric | 5.3 |
| Sandaracopimaric | 3.5 |
| Dehydroabietic | 2.2 |
| Elliotinoic | 1.3 |
| Pimaric | 0.0 |

The product potential of pinyon resin has been investigated by the National Paint, Varnish, and Lacquer Association (Westgate 1943) (fig. 29). Spirit and oleoresinous varnishes made from the resin had notable resistance to both hot and cold water, a characteristic which ordinary pine resins do not have, which suggests potential use of the resin in highly water-resistant varnishes. Use of the resin in place of copal resin in covering oil paintings has also been suggested (Colton 1948).

Pine oils are favored as frothing agents by the metallurgical industry—a potential market for oils derived from pinyon resin. The potential market for flotation frothers is a large one, particularly in the Southwest where copper mining is a large industry (appendix D, table 43). In Arizona alone, approximately 100 million tons of ore are currently treated annually by flotation methods (Soule' 1967). The quantity of frother used varies from 0.02 to 0.25 pound per ton of ore, averaging about 0.1 pound per ton (Knight 1967, Broderick 1967, Soule' 1967). Over 1.5 million pounds of pine oil were used as frothers in Arizona and New Mexico in 1960 (Fuerstenau 1962).

The physical and chemical requirements for a suitable frothing agent are very specific. Pine oils, principally obtained from steam distillation of pine stumps, are redistilled and fractionated to obtain a product with the desired characteristics (Gould 1967, Taggart 1945, Woodruff 1967):

| | |
|---|---|
| Initial boiling point - | 290° - 350° F. |
| End boiling point - | 370° - 430° F. |
| Specific gravity - | 0.92 - 0.95 |
| Refractive index - | 1.48 |
| Specific viscosity - | 2.5 at 70° F. |

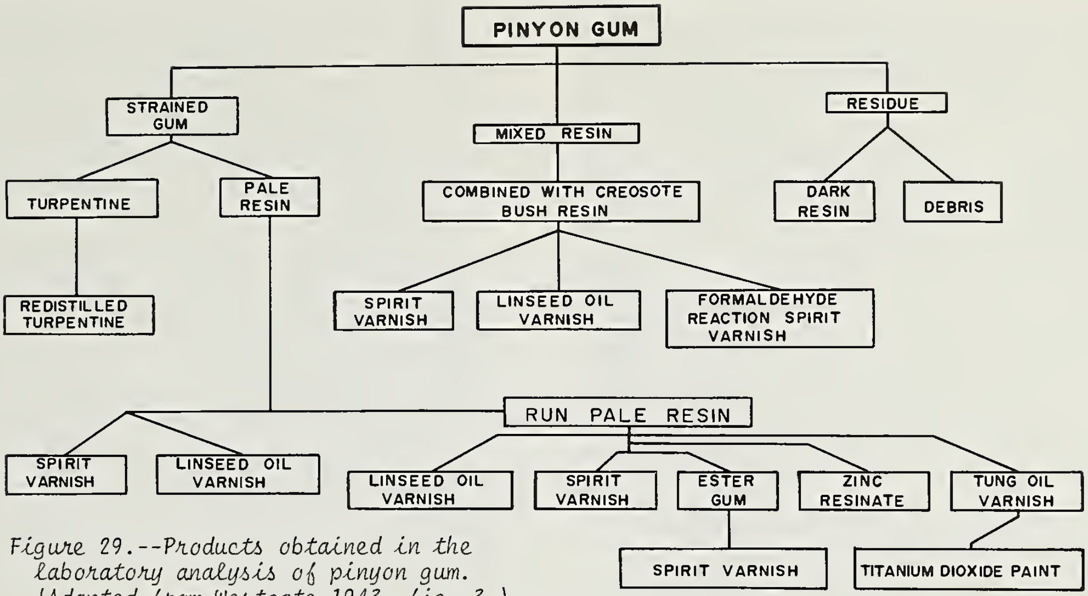



*Figure 29.--Products obtained in the laboratory analysis of pinyon gum. (Adapted from Westgate 1943, fig. 3.)*

Solubility and surface tension depression are also important characteristics of frothing agents. The primary frothing agent in the pine oils is terpineol, a hydroaromatic alcohol. Pinyon oil could be used as a frothing agent if it can be fractionated to obtain a product with the desired physical properties. An investigation of suitability would require distilling oil, fractionating the distilled product, and testing the fractions on a variety of ores (Gould 1967).

**Juniper species.**—The juniper woods contain appreciable quantities of oily, fragrant extractives rich in cedrol and associated essential oils. The compounds give the distinctive "cedar" fragrance for which the species are particularly noted. Eastern and southern species have been exploited commercially for the production of "cedarwood oil," marketed for a variety of uses in pharmaceuticals, perfumes, polishes, and insecticides. The foliage of several juniper species also contain extractives valuable for similar purposes, referred to and marketed as "cedar leaf oils."

The exact physical and chemical properties of the wood extractives of alligator and Utah juniper are not well known. Runeberg (1960) extracted Utah juniper heartwood with acetone, and obtained 9.3 percent total extractive, two-thirds of which was soluble in ether. Major identified chemical components of the extractive were thujopsene, cuparene, widdrol, carvacrol, nootkatin, hinokiic acid, and "Widdringtonia diol." Paper and gas chromatography also indicated the presence of $\beta$-thujaplicin and $\alpha$-cedrene. Western (or Sierra) juniper yielded 6.5 percent ether-soluble heartwood extractives (Kurth and Lackey 1948). Recovery from trunk wood included 0.9 to 1.25 percent volatile oil, consisting entirely of cedrol.

Oil is extracted in commercial quantities from alligator juniper in Texas (commonly identified there as J. mexicana Scheide & Deppe) (Berje 1966, Depew 1966, Lermond 1966). The limited information describing the oil of the Texas juniper (table 15) is probably directly applicable to alligator juniper elsewhere, and applicable to some extent to all southwestern junipers.

Oil is also distilled from waste, shavings, and sawdust from eastern redcedar, a species used in specialty furniture manufacture. The volatile oil recovered is reported to contain (Guenther 1952):

| | |
|---|---|
| Cedrol ($C_{15}H_{26}O$) | 3 to 14 percent |
| Cedrene ($C_{15}H_{24}$) | 80 percent |
| Cedrenol ($C_{15}H_{24}O$) | Small quantity |

Yields of oil range from about 1 to 3.5 percent by weight, depending on the proportion of heartwood (Guenther 1952, Panshin et al. 1950). Sapwood contains practically no oil.

The foliage of juniper species contains fragrant, oily extractives potentially valuable as essential oils. Northern white-cedar and eastern redcedar have been most commonly utilized for leaf oils (Bender 1963). The specific physical and chemical characteristics of the leaf oils of southwestern juniper species are unknown, but most conifer leaf oils have similar chemical composition; the main components

Table 15. — Physical and chemical properties of Texas cedarwood oil (adapted from information developed by Berje Chemical Products Inc. 1964)[1]

| Property | Type of oil: Dark | Light |
|---|---|---|
| Specific gravity (25°/25°C.) | 0.952-0.953 | 0.956-0.957 |
| Refractive index | 1.5050 | 1.5059-1.5062 |
| Optical rotation | -44.5° | -38.22° to -40.24° |
| Cedrol content | 21%-27% | 26%-32% |
| Solubility in: | | |
| Benzyl benzoate | Soluble in all proportions | |
| Diethyl phthalate | Soluble in all proportions | |
| Mineral oils | Soluble in all proportions | |
| Fixed oils | Soluble in all proportions | |
| Glycerine | Relatively soluble | |
| Propylene glycol | Relatively insoluble | |
| Alcohol | Clear to slight opalescence in 0.5 to 5.0 volumes of 90% alcohol | |
| Stability | Alkali: Moderately stable | |
| | Acid: Moderately stable to weak acids | |

[1]Texas cedarwood oil is the trade name given oils distilled from the juniper locally known as *J. mexicana* Schelde and Deppe, identified by Little (1953) as alligator juniper.

are members of the terpene and sequiterpene series (Bender 1963). Major chemical constituents of the leaf oils of three common Canadian juniper species (appendix D, table 44) included d-sabinene, d-sabinyl acetate d-limonene, pinene, cadinene, myrcene, and elemol (Couchman and Von Rudloff 1965, Von Rudloff 1963, Von Rudloff and Couchman 1964). Some of these compounds are likely to be major components of the leaf oils of southwestern junipers. The physical properties of leaf oils from southwestern junipers may also be somewhat similar to those for other juniper or related species (table 16).

Leaf oils are commonly extracted by steam distilling chopped or hammermilled foliage in a simple still (Bender 1963, U. S. Forest Serv. 1941b). Steam is generated in the bottom of the still, or is passed into the still from an outside source, and is directed up through the charge of material. The oils in the foliage are converted to vapor and discharged with the steam into a water condenser. The oil is skimmed off and chemically dried. Reported yields of leaf oils vary among species from 0.2 to almost 2 percent of the green weight, and average about 1 percent (Bender 1963, Panshin et al. 1950).

## Additional Pinyon Products

Unlike other woodland species, pinyon is valuable as a source of edible nuts and Christmas trees. Pinyon nuts are currently the most valuable product of the species, and provide seasonal self employment for many individuals with low income. Pinyon is also becoming increasingly popular for Christmas trees in the Southwest. These two products should rank high in any contemplated scheme of utilization.

### Pinyon Nuts

Pinyon nuts are borne in woody cones, as are the seeds of all pines, each cone containing about 10 to 20 seeds. Cones of pinyon

Table 16. — Physical properties of the leaf oils of white-cedar and juniper species (adapted from Bender 1963)

| Property | Northern white-cedar | Eastern redcedar | Rocky Mountain juniper |
|---|---|---|---|
| Specific gravity | 0.910 to 0.935 | 0.887 to 0.900 | 0.907 |
| Specific rotation | -5° to -16° | 25° to 59° | 41.7° |
| Refractive index | 1.4543 to 1.4687 | -- | 1.4862 |
| Boiling range (°C) | 160° to 250° | 150° to 180° | Half below 210°; half above 260° |

require most of three growing seasons to mature (Little 1938c):

| Year | Month | Stage of development |
|---|---|---|
| 1 | August | Winter buds containing cone primordia start to form. |
| | October | Winter buds fully formed. |
| 2 | May | Buds swell, scales around cone visible. |
| | June | Cones visible. Pollination occurs and scales close. |
| | July | Rapid cone and nut growth. |
| | August | End of season's growth. |
| 3 | May | Cones and nuts resume growth. |
| | July | Fertilization occurs. Cones and nuts full size, and seedcoats darken and harden. |
| | September | Cones and nuts mature. Cones open late in month. |
| | October | Entire crop of nuts fallen by end of month. |

Pinyons produce nut crops only at intervals of 4 to 7 years. Widespread heavy crops were produced in 1936, 1943, 1948, 1954, 1959, and 1965. The interval between crops on individual trees or in particular localities is shorter, usually 3 to 5 years. Crops are more frequent in favorable localities where the species flourishes, and are generally poorer and less frequent near the fringe of the type. Because of the staggered nature of crop years between areas, locally good crops generally occur somewhere every year.

The size of the nut crop varies with the particular year, but averages 1 to 2 million pounds annually (Hamilton 1965, Little 1941). Bumper crops may yield two to three times this amount. The bumper crop of 1936, considered the largest on record, totaled about 8 million pounds for Arizona, New Mexico, and Colorado (Little 1941).

Most pinyon nuts are handpicked from the ground by Indians. Occasionally tarpaulins or blankets are used to catch nuts shaken from the tree, or pack rat nests are robbed of their cache. Pickers receive $0.50 to $1.00 per pound, averaging about $0.70, from dealers. The nuts are cleaned and sacked by the dealer, and most are resold to wholesale firms in East and West Coast cities. Retail prices for the nuts range from approximately $1.00 to $2.50 per pound unshelled, and as high as $3.50 per pound shelled. Prices fluctuate considerably between "good" and "poor" crop years.

Pinyon nuts are commonly roasted in the shell before they are sold. Small quantities may be sold shelled or raw in the shell. The nuts are eaten directly, and are frequently used in candies and other confections. They can be stored raw and unshelled for 3 years or more under dry storage conditions. Raw shelled nuts or roasted nuts will become rancid within a few months, however (Botkin and Shires 1948).

Pinyon nuts have a relatively small proportion of shell since the shell is thin and not broken into compartments. The proportion of edible meat averages 58 percent of the weight of the unshelled nuts. Pinyon nut meats have a high food value in terms of protein, carbohydrate, and fat content (Botkin and Shires 1948):

| Component | Percent |
|---|---|
| Water | 2.9 |
| Protein | 14.5 |
| Fat | 60.1 |
| Carbohydrate | 18.7 |
| Crude fiber | 1.0 |
| Ash | 2.8 |

The protein fraction has a digestibility of 94.4 percent, and a nutritional value higher than most other nuts. Energy value of the nut meats ranges from 3,200 to almost 3,400 calories per pound (Little 1938b). The nuts of singleleaf pinyon contain much less protein and fat, and much more carbohydrate.

Since pinyon nuts constitute a regionally valuable crop, pinyon stands might be managed for nuts. Suggested management techniques include selection cutting to favor heavy crop trees, and cultural treatments such as fertilizing, cultivating, and irrigating (Little 1940, 1941). Nut production has been observed to improve along the boundaries of cultivated fields. Superior varieties could eventually be artificially propagated. Protection from excessive disease and insect damage could also influence crop yields, particularly during light crop years.

Some trees and stands consistently bear larger crops of nuts than other nearby trees or stands. Exceptional nut producers can usually

be identified by the number of old cones under the tree, or by the number of current 1- or 2-year cones (Little 1940). Blighted nuts under the tree from previous crops also provide some idea of the size of nut produced. Since cones are borne only at branch tips, trees with the greatest crown size and density will bear the most cones (fig. 30). Favoring these better crop trees when selectively cutting the stand will help maintain nut production.

Yields in the better natural stands have been estimated to reach 300 pounds per acre during good crop years (Hamilton 1965). At current prices this represents a gross income to the producer or picker of over $200 per acre. A similar return should be possible for intensively managed stands.

Pinyon is susceptible to attacks from a variety of insects that damage or kill cones and seeds. During the first year of cone development, larvae of gall midges cause most losses (Little 1943, 1944). The infested cones shrivel, dry, and fall from the tree. During the second year, cones and seeds may be destroyed by larvae of several species of moths and weevils, and by pinyon cone beetles. Losses are proportionately highest during light crop years when almost all of the cones may be destroyed. Under a program of intensive management for nut production, some control of heavy infestations would be desirable.

The production of empty seeds, referred to as blighting or blasting, is also common (Little 1939, 1944). Blighted nuts may be of normal size but contain only a small amount of shriveled, dry, brown material. Blighted nuts can usually be recognized by their light-colored shell or seedcoat.

Because nut crops occur infrequently and at varying locations, crop prediction is important to dealers and pickers. Pinyon nut crops can be predicted to some extent 2 years in advance, and with considerably greater accuracy 1 year in advance. Initial predictions for a locality can be made by examining a number of winter buds at the end of the growing season, 2 full years before crop maturity. Winter buds on pinyon include some containing many spur shoots along with one to three ovulate cones, and some containing principally staminate cones with a few spur shoots at the tip (Little 1938a). The winter buds containing ovulate cones are relatively small, pointed, and located primarily in the upper half of the tree crown. Buds having staminate or pollen-producing cones are larger, broader, more blunt, and are located on the lower half of the crown. To predict from bud examination, Little (1938a) suggests collecting 10 growing tips or leaders, composed of a large bud and one or more smaller buds, from the top of each of five previously heavy crop trees in an area. Cut each bud longi-

Figure 30.--Larger, spreading trees have more crown area and are usually the better nut producers.

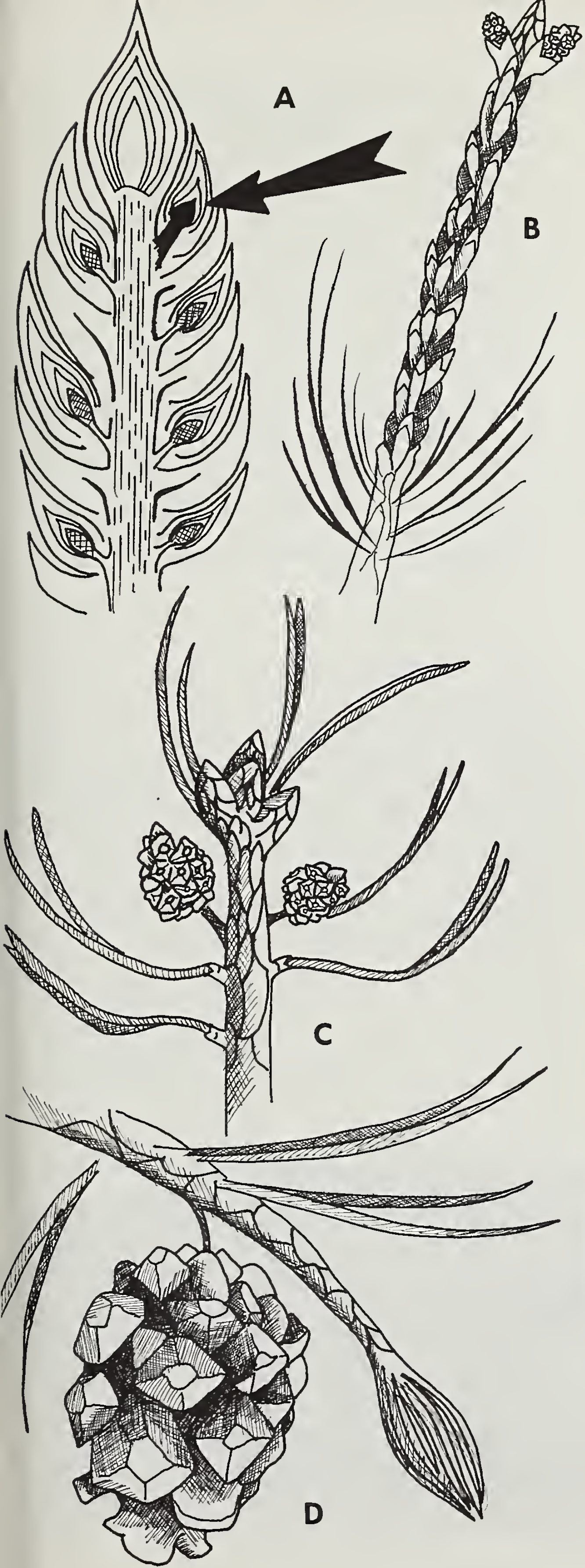



*Figure 31.--Typical characteristics of pinyon cones at four stages of development:*
*A, an ovulate cone primordium (0.05 inch long) in a winter bud;*
*B, two first-season cones at time of pollination in May or June;*
*C, year-old immature cones; and*
*D, a full-sized cone approaching maturity.*
*(Adapted from Little 1938a, 1939.)*

tudinally and examine for ovulate cone primordia. Primordia of ovulate cones can usually be recognized by (1) a larger, broader base than those of spur shoots, (2) single, paired, or triple occurrence, always at the tip of the bud, and (3) white coloration, compared to green spur shoot primordia (fig. 31) (Little 1938a). The conspicuous presence of cone primordia in a number of buds indicates a potential nut crop.

Predictions based on bud examination are tentative at best, since two additional seasons must pass before the crop matures. Losses from adverse weather conditions, disease, and insect damage can be severe.

The small cones become readily visible early in the following growing season, about 16 months before maturity (fig. 31). Thereafter the number of cones on the trees provides a more reliable means of crop prediction (fig. 32)(Little 1939). Small crops of first-year cones will usually indicate a crop failure at maturity since losses to disease and insects will be proportionately greater.

*Figure 32.--First-year pinyon cones as they appear at the beginning of the final season of growth. The heavy crop of first-year cones indicates a probable heavy nut crop at maturity.*

More accurate predictions can be made by July of the final growing season. Cones and nuts are full sized but still green. A sample of cones can be sectioned to examine the condition of the nuts. The nuts should be dark colored with solid, white contents. Some blighting is usual under the cone scales near the attached end of the cones.

**Pinyon Christmas Trees**

Pinyon Christmas trees, favored by residents of southwestern woodland areas for many years, are now popular on commercial Christmas tree lots, both in the Southwest and in adjacent population centers. Pinyon ranked 15th in number of Christmas trees produced nationally in 1964 (Sowder 1966):

| Year | Number of pinyon trees cut | National ranking |
|---|---|---|
| 1948 | 3,000 | 20 |
| 1955 | 163,000 | 15 |
| 1960 | 294,000 | 13 |
| 1962 | 233,000 | 16 |
| 1964 | 192,000 | 15 |

Numbers of trees shown are those actually reported cut. For wildling species such as pinyon, substantial numbers of trees are cut without authorization and are not reflected in reported figures.

In 1964, pinyon comprised almost one-fourth of all Christmas trees produced in the six-State area of Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico (Sowder 1965). The proportion of the market taken by pinyon is even greater in the States that have particularly large areas of pinyon-juniper woodland. The demand for pinyon Christmas trees in Utah increased from 10 percent of the market in 1952 to over 40 percent in 1960 (Kearns et al. 1962, Hunt and Poulsen 1964). Demand for pinyon trees had declined since 1960, apparently due to increased substitution of artificial trees and increased sale of plantation-grown trees.

Pinyon Christmas trees are harvested from natural stands on Federal, State, and private lands. The species has not been produced to date in commercial plantations. Younger pinyon stands of open to medium density yield large numbers of well-shaped Christmas trees (fig. 33). Young trees of desirable form are also found on the perimeter of older stands, and adjacent to open grassland areas. Some pinyon Christmas trees are cut and marketed by commercial operators, who bid on a specified number of trees in a tract. Most of the trees, however, are cut by families who purchase single-tree permits. Average prices per tree are (Hunt and Poulsen 1964, LeBaron 1967, 1968):

| Transaction | Price per tree |
|---|---|
| Single-tree permit (8 feet or shorter) | $1.00 |
| Stumpage, commercial sale | 0.25-0.60 |
| Wholesale price to truckers | 1.60 |
| Wholesale price delivered to yard | 2.25 |
| Commercial retail price | 4.00-5.00 |

In a recent study, pinyon Christmas tree potential was investigated on a selected 640-acre Section of State-owned lands in northern Arizona (Northern Ariz. Univ. 1966). The Section currently supports approximately 6,260 salable Christmas trees (table 17). An additional 3,030 small trees (0-3 feet) were considered good potential future Christmas trees. The inventory also indicated that approximately 6,490 trees have been removed from the Section by unauthorized cutting, which emphasizes the need for closer supervision of potential Christmas tree areas.

*Figure 33.--Young pinyon stands often yield large numbers of desirable Christmas trees.*

Table 17. — Christmas tree potential in pinyon stands on one Section of State-owned land in northern Arizona (Northern Arizona University 1966)

| Tree height class[1] (Feet) | Tree grade | Trees per acre[2] | Total trees in Section |
|---|---|---|---|
| | | Number | |
| 0-3 | Good | 16.8 | 3,030 |
| | Cull | 7.2 | 1,290 |
| 4-6 | Good | 2.8 | 510 |
| | Utility | 11.2 | 2,010 |
| | Cull | 17.9 | 3,220 |
| 7-9 | Good | 3.9 | 710 |
| | Utility | 16.8 | 3,030 |
| | Cull | 24.0 | 4,330 |
| 9+ | | 23.6 | 4,240 |
| Stumps | | 36.1 | 6,490 |

[1] The study considered trees 0-3 feet tall as reproduction; 4-6 and 7-9 feet tall as salable; and 9+ feet tall as unsalable.
[2] Number of trees per acre indicated for the 180-acre portion of the Section actually supporting pinyon stands.

Pinyon trees naturally develop many of the attributes of a good Christmas tree—many buyers judge trees largely on their physical appearance without regard to species. Desirable characteristics of a Christmas tree include:

1. Symmetrical form;
2. Dense foliage;
3. Natural fragrance;
4. Deep green color;
5. Limb strength sufficient to hold ornaments without sagging;
6. Retention of needles, or minimal needle drop for several weeks following cutting.

Grading systems have been developed to classify Christmas trees according to shape or form class and foliage density. A national standard for Christmas trees (appendix D, table 45) includes three standard grades, "U. S. Premium," "U. S. Choice," and U. S. Standard" (U. S. Dep. Agr. 1962). Trees that fail to meet the lowest grade requirements are classified as "Culls."

Christmas tree grading rules in common use often emphasize the slender, tapered form of the firs and spruces, and degrade trees with broader or more ovoid forms. Such grading rules unnecessarily penalize tree species such as pinyon, which seldom have the tapered form. A system of grading was therefore developed specifically for pinyon Christmas trees by Utah State University (Kearns et al. 1962). Four form classes are recognized—tapered, triangular, oblong, and round—all of which are considered equally acceptable (fig. 34). Trees are graded entirely on symmetry, foliage density, color, and deformities (table 18). The use of standardized grades provides a common basis for transactions between producers and wholesalers or dealers (Brundage 1965).

The decline in demand for pinyon trees is partly due to scarcity of marketable trees. Many of the available and accessible stands have been picked over until few high-quality Christmas trees remain. The quality of trees in natural stands could be improved in time by cultural treatments such as thinning and shearing. Thinning heavy stands and opening older stands will encourage growth of trees of acceptable form and density. Shearing, commonly practiced in plantations, provides a means of increasing density and developing a uniform, conical shape. The leader of the tree is sheared or cut back at a desirable interval above the last whorl to stimulate adven-

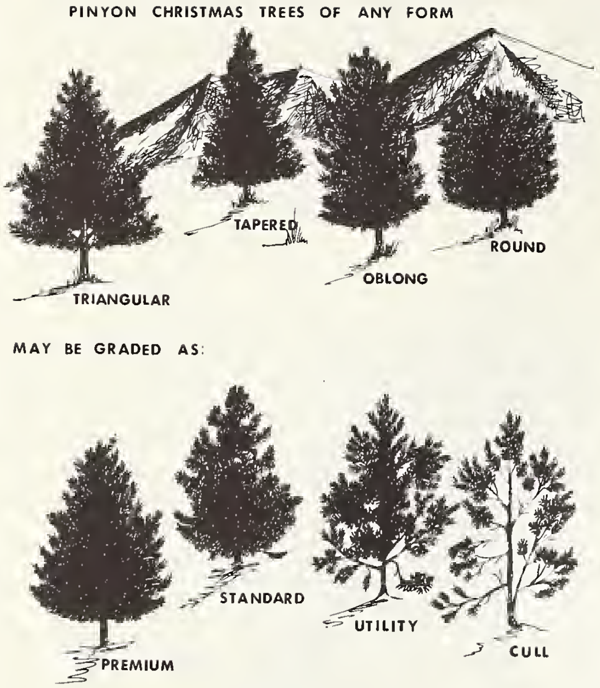



Figure 34.--Pinyon Christmas trees occur in four form classes (above), all of which are acceptable on the market. Quality grades should be based upon symmetry and density as illustrated below. (Adapted from Kearns et al. 1962.)

titious budding and create another whorl. Side branches are similarly sheared to attain a symmetrical conical shape. Pine species are usually sheared in early summer, as soon as new growth reaches or starts to exceed the desired form. Several promising pinyon Christmas tree production areas in New Mexico have been designated for more intensive management, under the supervision of New Mexico State Forestry Division personnel.

## MANAGEMENT IMPLICATIONS OF UTILIZATION

The woodland species represent a vast source of wood fiber, potentially useful for many wood products. They also affect, either directly or indirectly, the production or recovery of other resources on the area. Large-scale utilization of these species will be influenced by land management objectives and programs to improve range forage conditions, water yields, or wildlife habitat conditions. The woodland species are generally detrimental to forage production and water yield, but in limited quantities are beneficial to wildlife, and provide esthetic values. Utilization of these species for wood products, if carefully coordinated with land management for other resources, could capitalize on the complementary nature of these resource management objectives.

Table 18. — Minimum standards for pinyon Christmas tree grades (adapted from Kearns et al. 1962)

| Tree characteristic | Tree grades[1] | | |
|---|---|---|---|
| | Premium | Standard | Utility |
| Density | Dense — foliage thick, main stem not visible | Medium — main stem visible in places | Light — foliage open, main stem visible |
| Symmetry — balanced appearance of faces | Balanced on four faces | Balanced on three faces | Balanced on two adjacent faces |
| Color | Deep green | Deep green | May be altered |
| Deformity — any defect that detracts from appearance or shipping quality | Minor deformity allowed | Minor deformity allowed; noticeable deformity allowed in otherwise premium tree | Minor deformity allowed; noticeable deformity allowed in otherwise premium tree |

[1]Any tree that fails to meet requirements for the utility grade is a cull.

## Removal of Woodland Species as a Land Treatment

On lands where forage production and water yield hold high priority, the presence of pinyon, juniper, and other woodland species is undesirable. The trees compete with desirable forage for space and water, and litter from the trees inhibits the growth of some of the major grass species (Jameson 1966). The trees also reduce potential water yields from the area through interception, water use, and evapotranspiration. Many woodland stands are becoming more dense and are invading adjacent open areas, intensifying the problem (Cotner 1963a, Arnold et al. 1964). Eradication or control, principally to improve forage conditions, has been practiced in Arizona since the 1940's. More than 1.2 million acres of the pinyon-juniper type in the State had been treated by 1961 (Cotner 1963a), and additional acreage has been treated since (Chilson 1964, Warskow 1967), although recent control measures have generally been restricted to relatively small, selective areas. Large areas of the woodland type have also been treated in other southwestern States.

Gambel oak is occasionally reduced or eradicated on selected areas to improve forage conditions (Jefferies 1965), to increase water yields (Johnston et al. 1969), or to enhance timber regeneration (Pearl 1965). Because Gambel oak sprouts prolifically, areas must be periodically re-treated, usually with herbicides.

Figure 35.--Woodland trees are uprooted from range and watershed areas by pulling a heavy cable between two tractors.

Figure 36.--Down trees and debris remain on an area cabled more than 10 years previously. Smaller trees escaped the cabling process.

### Methods

A variety of methods have been used to reduce or control pinyon-juniper stands on range and watershed areas. Large areas have been treated by "cabling" or "chaining," in which a heavy cable or anchor chain is dragged between two large tractors (fig. 35). Bulldozing or pushing has also been widely used to remove individual trees. Hand clearing with ax and saw has been employed to a lesser extent. All of these methods leave the felled trees and associated slash on the ground (fig. 36). Slash disposal and other followup treatments are often necessary to adequately clear the area for the intended use.

Broadcast burning has been reasonably successful on areas suited to burning. Aro (1971) found burning to be the most effective and least expensive conversion technique, in stands where vegetation is dense enough to carry a fire. Individual tree burning, in which the base of the tree is heated or burned, has been used on a limited scale. Tree-killing chemicals are available but have not been used extensively. Burning and chemical control methods are unique in that they leave the dead trees standing. The trees occupy less area than they would felled, and they remain in better physical condition for subsequent utilization.

Tree crushers or "tree eaters" are now being used to treat selected areas suited to their operation. These large machines move across the area, chipping or cutting entire trees into small pieces and distributing the chipped material over the area.

### Costs

Costs of control measures on pinyon-juniper woodlands provide some idea of harvesting costs for the species, and stand conditions represented. Costs of control also represent a "negative value" of the woodland resource on that particular area. Any amount less than this could be spent to encourage and assist utilization of the material, to the economic advantage of both utilization and the control program.

Costs of tree removal vary widely between areas, stands, and control methods. Cabling or chaining is the cheapest method now in common use, with reported costs ranging from less than $1 to about $6 per acre (table 19). Bids awarded for cabling pinyon-juniper areas on Salt River Project watersheds during the period 1964-66 ranged from $3.97 per acre to $6.20 per acre, and averaged $4.99 per acre (Warskow 1967). Costs of individual tree operations such as pushing, hand cutting, or single-tree burning vary widely with the size and density of the stand.

Table 19. — Costs per acre of control treatments in southwestern pinyon-juniper stands, by stand size (mature or small) and density (heavy, medium, or light)

| Operation and method | Stand | Density | Cost per acre |
|---|---|---|---|
| | | | Dollars |
| Tree clearing: | | | |
| Cabling or chaining | M | H | [1]5.00 - 6.00 |
| | M | M | [2]Ave. 3.50 |
| | M | L-M | [3]1.22 - 2.33 |
| | S | L-M | [3].95 - 1.46 |
| Pushing | M | H | [1]8.00 - 14.00 |
| | M | L-M | [2]5.00 - 7.00 |
| | M | L-M | [3]3.72 - 10.90 |
| | S | L-M | [3]3.13 - 7.66 |
| Hand cutting, piling | M | H | [1]45.00 - 55.00 |
| | M | H | [4]Ave. 45.02 |
| | S | L | [2]Ave. 6.00 |
| Burning individual trees | M | L-M | [3]3.17 - 13.43 |
| | S | L-M | [3]1.91 - 7.70 |
| | S | L | [2]1.75 - 1.90 |
| Cleanup following pushing or cabling | | | [1]2.00 - 6.00 |
| | | | [2]Ave. 6.00 |
| Slash burning | | | [1].50 - 1.00 |

[1] Worley and Miller (1964)
[2] N. Mex. Inter-Agency Range Comm. (1968).
[3] Cotner (1963a); predicted costs, based on analysis of experienced costs.
[4] Miller (1971).

Most control methods involve initial removal of the existing stand, followed by periodic control measures to prevent reestablishment. The costs of subsequent control depend largely upon the rate of regrowth (or site quality) and elapsed time between re-treatments. Procedures have been developed for identifying optimum stand density and timing of tree removal for various control methods (Cotner 1963b, Jameson 1971).

Costs per unit of wood material are more meaningful than per-acre costs for utilization purposes, although they are in many instances an average of extremes. Costs in table 19 represent approximate average "felling" costs per cord of $1-$2, $2-$4, and $5-$17 for cabling, pushing, and hand cutting, respectively. A large part of the hand cutting cost is often expended on trees too small to contribute much to total volume removed. Miller and Johnsen (1970) found the cost of cutting the larger alligator juniper trees (9 inches and over at stump height) to be $9.29 per acre, or about $4.50 per cord.

The costs discussed here represent only those incurred in pushing, cutting, or otherwise felling the trees. Utilization of the material would involve the additional costs of limbing and bucking.

### Influence on Utilization

Substantial mutual advantages could be derived from coordinating utilization operations with control programs for woodland species. Live, standing trees could be harvested in areas designated for treatment, with physical or financial assistance from the other resource management interests represented. Alternatively, dead material could be harvested either on the ground after chaining, cabling, or pushing, or standing after burning or chemical treatment.

Pinyon can best be utilized from live stands, since it is nondurable and deteriorates quickly after control operations. Some pinyon might logically be utilized as pulpwood, for which green unstained material is desired. The juniper species remain durable for many years, however, and offer an extended opportunity for utilization. Downed material could conceivably provide a resource base for chemical, fiber, or chip products, such as charcoal, pulp products, and fiber and particleboards. The larger material

*Figure 37.--The bark on burned Utah and one-seed juniper trees remains tight almost indefinitely, except for basal portions of the tree that were directly exposed to the flame.*

could also be utilized for more commonplace products such as fuelwood, fenceposts, and sawn stock for novelties.

Utilization of the woodland species, either standing or down, is at best a marginal operation. Additional incentives for utilization are needed to appreciably increase use of these species. In the long run, incentives may develop through new product and process technology, and a shortage of wood fiber. In the near future, however, incentives will probably have to come from other land management programs. Utilization may be encouraged, for example, by control treatments that in some way condition or prepare the trees for use. Preparation for utilization could involve mapping and marking areas where utilization opportunities are best, bunching trees in scattered stands, or debarking the trees prior to use.

The adherence of bark to downed material particularly discourages utilization practices such as chipping on site for products requiring barkfree chips. The fibrous bark of Utah and one-seed junipers remains tight for many years following control measures, except for the portion of flame-killed trees directly exposed to the flame of the torch (Johnsen 1967)(fig. 37). Alligator juniper trees appear to lose their bark much more quickly (fig. 38), although irregularly and perhaps not soon enough to accommodate early utilization of the material. Natural bark loss appears to be stimulated by quick cambial kill such as that obtained from direct exposure to flame or chemical reaction. Chemical debarking has been used experimentally with some success in commercial pulpwood species. With chemical control measures for woodland species, it may be possible to both kill the trees and debark them in preparation for utilization.

*Figure 38.--Alligator junipers killed by burning lose their bark more quickly than other junipers. Patches and strips still remain, however, years after treatment.*

### Effects of Removal on Other Resources

If utilization of the woodland species is closely tied to control programs, a probable economic necessity, the extent of utilization will largely depend on how well removal meets the objectives of managing other resources. The results of past control programs provide some indication of effects of removal and probable emphasis upon similar land treatment in the future.

### Range

The primary objective of most control or treatment programs has been to improve range conditions. Pinyon and juniper are almost worthless as forage for livestock, although some foliage may occasionally be consumed (Pase 1966, Stoddart and Smith 1955). The trees compete with herbaceous understory for space through the inhibiting effects of litter, and in many instances may also compete for available water (Skau 1964). Removal of trees usually increases herbage production, although growth of perennial grasses may not be immediately affected (Brown 1965). Sagebrush, cactus, or other undesirable plants in the understory may also increase following treatment at the expense of more desirable forage species. Some care in selecting potential control areas is required. Guidelines suggested by Daniel et al. (1966) for selection of treatment areas include (1) slopes less than 15 percent, (2) relatively open tree canopy (3) sufficient understory of valuable forage species for seed stock, and (4) sites with a relatively high proportion of pinyon. If existing understory forage is sparse or potential is restricted by a heavy tree canopy, tree removal may have to be followed by direct seeding to establish forage species. Stands that are predominantly pinyon frequently indicate areas of higher precipitation; in addition, pinyon does not reestablish as quickly as juniper species.

Under favorable conditions for herbage growth, forage may eventually increase 200 percent or more (Arnold et al. 1964, Chilson 1964, McCorkle and Ray 1965, Reynolds 1962). Improved animal weight gains and reduced livestock handling costs are often fringe benefits of control programs. Cotner and Kelso (1963) estimate the dollar value of pinyon-juniper control on rangelands at $1.19 to $3.89 per acre, depending upon interest rates and management variables.

### Wildlife

The woodland species provide both protective cover and some food for wildlife, including elk, deer, turkey, and smaller game such as rabbits and squirrels. The relative importance of the woodland species in the diet of wildlife is not well understood. Pinyon, juniper, and Gambel oak are all eaten to some extent by mule deer, however (Lamb 1964; Neff 1966, 1967; U. S. Forest Serv. 1967b) (fig. 39), and pinyon nuts, juniper berries, and Gambel oak acorns seasonally provide large quantities of food for both large and small game. Gambel oak is a particularly important source of browse, mast, and cover for wildlife throughout the ponderosa pine type (Reynolds et al. 1970). Thus extensive eradication of woodland species might harm the wildlife resource, suggesting a need for compromise.

Some control of pinyon-juniper can be beneficial to wildlife, however. Arizona studies indicate that removal or reduction of pinyon-juniper overstory on selected areas can substantially improve vigor and sprouting in browse species (Jantzen 1959; McCulloch 1961, 1963). Reynolds (1964) found that deer and elk use of the pinyon-juniper type was greatest at intermediate tree densities. Shrub abundance, which increased with tree overstory up to intermediate densities, was the most important factor related to game use. The study concluded that tree cover should be thinned to about 150 stems per acre on areas reserved for game habitat.

Range improvement programs can be effectively coordinated with wildlife needs by interspersing stringers or islands of cover in cleared areas (fig. 40), and by leaving stands of intermediate density on topographic areas favored by wildlife (N. Mex. Inter-Agency Range Comm. 1968, Reynolds 1964).

### Watershed

Throughout the Southwest one of the common objectives of wild-land management is to increase water yields from natural watersheds. Removal or reduction of woodland species has gained considerable attention as a possible means of increasing water yields. Although the pinyon-juniper type occupies large land areas, the lower precipitation and higher radiation levels and evaporation rates in these areas make improvements in water yields difficult (Dortignac 1960). Recent studies have been unable to show that pushing, cabling, or burning

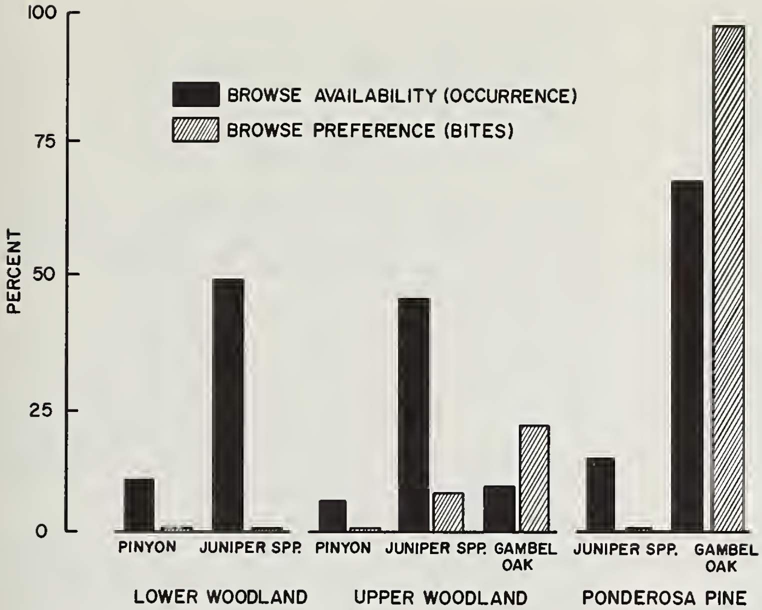



*Figure 39.--Availability and preference of woodland species utilized as browse by mule deer. (Adapted from Neff 1966, 1967.)*

pinyon-juniper stands has any significant effect on off-site water yields (Brown 1965, Collins and Myrick 1966, Skau 1964). The most intensive studies have been carried out on volcanic soils, however, leaving unanswered the question of response on other soil types.

Replacement of heavy stands of Gambel oak with "shallow rooted" plants has been reported to reduce soil moisture depletion (Johnston et al. 1969). Gambel oak occurs in Arizona primarily as an intermingling minor species, however, rather than a dense brush cover that might affect water yields.

In summary, possibilities for increasing water yields through removal or reduction of woodland species in Arizona are nor promising. Unless new evidence is developed, these species probably will not be removed on a large scale for water yield improvement alone.

## Implications for Resource Availability

The potential utilization of woodland species is unattractive to private industry, some of the principal reasons being the low volume of material per unit area, associated high harvesting costs, and poor form and quality for most uses. These combine to make the resource economically unavailable. Wild-land resource management programs that involve removal or control of these species offer opportunities for encouraging utilization. Where potential values of other resources are high, some form of assisting or subsidizing commercial utilization activities may be warranted.

Private enterprises interested in using the woodland species will also encounter a modified concept of timber as a resource. Timber is commonly treated as a renewable or flow

*Figure 40.--Strips or patches of trees constituting wildlife "islands" have been left on many treated areas.*

resource, presumably available in some sustained quantity indefinitely. In contrast, the woodland species have not generally been managed to perpetuate the resource. Management of areas supporting these species commonly involves tree removal or control programs. For practical purposes the woodland species must be considered a static or stock resource. In any particular area, then, the resource will be exhausted over time, obliging the industry or mill dependent upon the resource to move, discontinue operation, or reach successively longer distances for raw material.

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## APPENDIX A

## GLOSSARY

**Adventitious bud.**—A bud that develops along the main stem or branches of a tree, often remaining dormant indefinitely unless the primary growing tip is injured.

**Annual growth or annual increment.**—The layer of material added to a tree each year, consisting normally of one growth ring or annual ring.

**Branch whorl.**—A row of branches spaced around a tree at one general height on the stem: in many coniferous species, one whorl is added each year.

**Brightness.**—In pulp manufacture, a standard measure of the relative reflectivity or lightness of a sheet of pulp or paper.

**British thermal unit - (B.t.u.).**—A measure of heat content or heat output: the quantity of heat required to raise the temperature of a pound of water 1° F.

**Cellulose.**—A major chemical constituent of wood cell walls: the principal component remaining in chemically prepared wood pulp.

**Defect.**—Any irregularity in or on wood that may affect or limit its suitability for a particular end use.

**Density.**—Mass per unit volume, usually expressed as pounds per cubic foot: see also "specific gravity."

**Exothermic reaction.**—A reaction characterized by creation and release of heat: in charcoal manufacture, the reaction during the coaling or carbonization period, in which the wood is converted to charcoal through controlled combustion.

**Extractives (wood).**—Substances contained in wood that are not an integral part of the cellular structure, and can be dissolved out with water, alcohol, ether, benzene, or other solvents.

**Fiber (wood).**—A single wood cell, typically long and slender with pointed ends.

**Fiberboard.**—Any of a variety of building and insulating panel products manufactured by bonding processed wood fibers under heat and pressure.

**Fiber saturation point.**—Point at which all free water has evaporated from wood cell cavities, but cell walls remain fully saturated: drying below fiber saturation point results in shrinkage of the wood.

**Forest type.**—A classification of forest land based on the predominant tree species, the type name being that of the species.

**Frothing agent.**—Any nonsoluble oil or similar chemical used in mineral froth flotation processes.

**Grain (wood).**—The arrangement and alignment of fibers in wood: distinctive or decorative grain patterns are often referred to as "figure."

**Hardness.**—Resistance to impression or marring, usually expressed as the force in pounds required to embed a steel ball of a standard diameter.

**Hardwood.**—Wood from any deciduous or broad-leaved tree (oak, elm, ash, etc.).

**Heartwood.**—Inner portion of a woody stem, extending from pith to sapwood, usually darker in color and with lower moisture content than sapwood.

**Hemicellulose.**—A group of carbohydrates found in wood cell walls in intimate association with cellulose, and having many of the same chemical properties as cellulose: the two together are commonly referred to as "holocellulose."

**Index of refraction (refractive index).**—A physical property of liquids useful in characterizing the substance.

**Inventory (timber).**—The measurement of volume, species composition, stand structure and stocking, growth, quality, and other characteristics descriptive of the timber resource.

**Juvenile wood.**—Wood developed during the first few years of the life of the tree; often more rapidly grown, less dense, and weaker than subsequent wood in the same tree.

**Leader.**—The growing tip of the main stem of a tree.

**Lignin.**—A major chemical constituent of wood cell walls, acting as a binding agent: largely removed during preparation of chemically digested wood pulp.

**Modulus of elasticity (MOE).**—A measure of the stiffness or rigidity of a material; i.e., resistance to deflection.

**Modulus of rupture (MOR).**—A measure of the load, slowly applied, that a member or material will support for a short time.

**Moisture content.**—The quantity of water in wood, expressed as a percentage of the weight of the ovendry wood.

(a) **Green wood.**—Wood as it comes from the tree, with a moisture content ranging from 30 percent in some heartwood to well over 100 percent in some sapwood.

(b) **Air-dry wood.**—Wood that has dried sufficiently to reach equilibrium with surrounding conditions, commonly assumed to be approximately 12 percent moisture content.

**Oleoresin.**—The pitch, or sap originating in the living cells of coniferous trees: a mixture of essential oils (such as turpentine) and natural resins (such as rosin).

**Optical rotation.**—A physical property of liquids or solutions useful in characterizing the substance.

**Ore flotation.**—A process for separating minerals from waste material, in which a nonsoluble oil such as pine oil is added to the pulverized ore and water mixture. Air is blown through the agitated mixture forming an oil froth that carries the valuable mineral to the surface.

**Ovendry.**—A term applied to material that has been dried in an oven until all moisture has been removed.

**Particleboard.**—Any of a variety of engineered panel building products made of wood particles bonded together with adhesive under heat and pressure.

**Resin.**—The solid organic compounds found in oleoresin; also, a general term commonly applied to the extractives in coniferous woods.

**Rosin.**—A vitreous, hydrophobic, solid organic material remaining after turpentine and other volatile components have been removed from pine oleoresin. Pine rosin consists of a mixture of diterpene resin acids.

**Saponification number.**—A value useful in the analysis and description of oils, indicating the milligrams of potassium hydroxide needed to saponify 1 gram of the substance.

**Sapwood.**—Outer portion of a woody stem, extending from bark to heartwood, usually lighter in color and with a higher moisture content than heartwood.

**Seasoning.**—Removing the water from wood by exposing to air for a period of time, or by controlled heating in a kiln.

**Shrinkage.**—Contraction of wood caused by drying below fiber saturation point.

**Softwood.**—Wood from any coniferous tree (pine, spruce, fir, etc.).

**Specific gravity.**—Density or weight of wood, expressed as a decimal proportion of the weight of an equal volume of water.

**Specific viscosity.**—The viscosity or resistance to flow of a liquid expressed in terms of the viscosity of a common, substance, usually water.

**Stumpage.**—A term commonly applied to the valuation or price paid per unit volume for standing timber.

**Tall oil.**—A natural mixture of rosin acids, fatty acids, and unsaponifiables obtained from acidification of soap skimmings from black pulp liquor: a source of turpentine and rosin.

**Terpene.**—An unsaturated organic compound occurring in most essential oils and oleoresins of plants.

**Texture (wood).**—An expression of the appearance and working qualities of wood resulting from the general size of cells and other wood elements: woods with small cells are "fine textured."

**Turpentine.**—A volatile oil obtained by distillation of oleoresin or resinous wood, or as a byproduct of sulfate pulping: consists of monoterpene hydrocarbons, with some sesquiterpenes.

**Veneer.**—Thin layers or sheets of wood cut from a log with rotary lathe or slicer: the individual layers of wood making up a sheet of plywood.

**Volume table.**—A table of board-foot, cubic-foot, or product volume contained in standing trees of various diameters and heights, assuming average form factors or taper.

**Wood pulp.**—Pulp manufactured by either chemical or mechanical means from wood.

(a) **Mechanical wood pulp (ground wood).**—Pulp produced by mechanically grinding or reducing the wood to fibers.

(b) **Chemical wood pulp.**—Pulp produced by chemically digesting the wood, removing most of the lignin and leaving principally cellulose fiber.

# APPENDIX B

## TIMBER STATISTICS

Table 20. — Number of trees, basal area, and volume per acre of pinyon and juniper in the pinyon-juniper woodland type in northern Arizona and New Mexico (adapted from Howell 1940, tables 18, 19, and 20)

| Diameter, stump high (inches) | Pinyon | | | | Juniper | | | |
|---|---|---|---|---|---|---|---|---|
| | Trees | Basal area | Volume | Cords | Trees | Basal area | Volume | Cords |
| | No. | Sq.ft. | Cu.ft. | No. | No. | Sq.ft. | Cu.ft. | No. |
| 1 | 32.1 | 0.128 | — | — | 19.8 | 0.093 | — | — |
| 2 | 55.8 | 1.116 | — | — | 27.5 | .490 | — | — |
| 3 | 43.2 | 1.598 | 3.20 | 0.05 | 24.7 | .982 | 8.22 | 0.12 |
| 4 | 32.5 | 2.080 | 12.03 | .18 | 20.0 | 1.376 | 9.32 | .15 |
| 5 | 26.5 | 2.862 | 11.76 | .18 | 15.6 | 1.757 | 10.81 | .17 |
| 6 | 21.8 | 3.553 | 20.72 | .31 | 12.8 | 2.023 | 11.75 | .19 |
| 7 | 17.6 | 3.837 | 25.85 | .39 | 10.7 | 2.300 | 13.89 | .22 |
| 8 | 13.7 | 3.781 | 30.78 | .46 | 8.8 | 2.468 | 14.77 | .23 |
| 9 | 10.0 | 3.420 | 33.02 | .49 | 7.1 | 2.518 | 15.83 | .25 |
| 10 | 7.0 | 2.940 | 36.24 | .54 | 5.6 | 2.448 | 14.43 | .23 |
| 11 | 5.3 | 2.740 | 34.70 | .52 | 4.8 | 2.532 | 20.85 | .32 |
| 12 | 4.1 | 2.563 | 31.52 | .47 | 3.9 | 2.440 | 19.99 | .31 |
| 13 | 3.3 | 2.508 | 31.38 | .47 | 3.3 | 2.420 | 20.11 | .31 |
| 14 | 2.4 | 2.112 | 26.62 | .40 | 2.7 | 2.275 | 18.89 | .30 |
| 15 | 1.8 | 1.800 | 22.10 | .33 | 2.2 | 2.135 | 17.95 | .28 |
| 16 | 1.3 | 1.476 | 17.24 | .26 | 1.8 | 1.964 | 16.74 | .26 |
| 17 | 1.0 | 1.280 | 14.36 | .22 | 1.5 | 1.824 | 15.96 | .25 |
| 18 | .7 | .991 | 10.35 | .16 | 1.1 | 1.524 | 13.10 | .20 |
| 19 | .5 | .798 | 8.09 | .12 | 1.0 | 1.518 | 13.28 | .20 |
| 20 | .3 | .525 | 5.34 | .08 | .8 | 1.342 | 11.68 | .19 |
| 21 | .2 | .390 | 3.81 | .06 | .7 | 1.277 | 11.91 | .19 |
| 22 | .2 | .430 | 4.02 | .06 | .6 | 1.183 | 10.66 | .16 |
| 23 | .1 | .239 | 2.18 | .03 | .5 | .995 | 8.86 | .14 |
| 24 | .1 | .264 | 2.30 | .03 | .5 | 1.084 | 9.77 | .16 |
| 25 | .1 | .145 | 1.19 | .02 | .4 | .895 | 9.19 | .14 |
| 26 | .1 | .159 | 1.26 | .02 | .2 | .601 | 5.56 | .09 |
| 27 | .1 | .171 | 1.31 | .02 | .2 | .648 | 5.76 | .09 |
| 28 | .1 | .185 | 1.42 | .02 | .1 | .348 | 2.99 | .05 |
| 29 | | | | | .1 | .374 | 3.09 | .05 |
| 30 | | | | | .1 | .399 | 3.19 | .05 |
| 31 | | | | | .1 | .427 | 3.33 | .05 |
| 32 | | | | | .1 | .228 | 1.73 | .03 |
| 33 | | | | | .1 | .242 | 1.77 | .03 |
| 34 | | | | | .1 | .257 | 1.81 | .03 |
| 35 | | | | | .1 | .272 | 1.86 | .03 |
| 36 | | | | | .1 | .292 | 1.91 | .03 |
| Total | 281.9 | 44.091 | 392.79 | 5.89 | 179.7 | 45.951 | 350.96 | 5.50 |

Table 21. — Total number of trees and volume per acre, by crown density classes, in pinyon-juniper stands in northern Arizona and New Mexico (adapted from Howell 1940, table 16)

| Crown density (Percent) | Pinyon and juniper trees | Volume | Cords |
|---|---|---|---|
| | Number | Cu. ft. | Number |
| 5 | 20 | 37 | 0.6 |
| 10 | 52 | 83 | 1.3 |
| 15 | 89 | 138 | 2.1 |
| 20 | 133 | 200 | 3.1 |
| 25 | 178 | 250 | 3.8 |
| 30 | 230 | 350 | 5.4 |
| 35 | 270 | 441 | 6.8 |
| 40 | 300 | 520 | 8.0 |
| 45 | 340 | 605 | 9.3 |
| 50 | 370 | 675 | 10.4 |
| 55 | 400 | 745 | 11.4 |
| 60 | 425 | 820 | 12.6 |
| 65 | 440 | 875 | 13.5 |
| 70 | 460 | 950 | 14.6 |
| 75 | 480 | 1,010 | 15.5 |
| 80 | 500 | 1,075 | 16.5 |
| 85 | 520 | 1,130 | 17.4 |
| 90 | 540 | 1,195 | 18.4 |
| 95 | 560 | 1,270 | 19.5 |
| 100 | 610 | 1,325 | 20.4 |
| 105 | 680 | 1,390 | 21.4 |
| 110 | 750 | 1,450 | 22.3 |
| 115 | 845 | 1,500 | 23.1 |
| 120 | 935 | 1,580 | 24.3 |
| 125 | 1,000 | 1,615 | 24.8 |
| 130 | 1,090 | 1,685 | 25.9 |
| 135 | 1,175 | 1,740 | 26.8 |
| 140 | 1,240 | 1,800 | 27.6 |
| 145 | 1,300 | 1,840 | 28.3 |
| 150 | 1,400 | 1,895 | 29.1 |

Table 22. — Number of trees, basal area, and volume per acre of pinyon and Utah juniper in the upper and lower woodland zones[1] below the Mogollon Rim

| Diameter, breast high (Inches) | Pinyon | | | | | | Utah Juniper | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper zone | | | Lower zone | | | Upper zone | | | Lower zone | | |
| | Trees | Basal area | Volume | Trees | Basal area | Volume | Trees | Basal area | Volume | Trees | Basal area | Volume |
| | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. |
| 0.1-4.9 | 3.8 | 0.13 | 0.7 | 13.3 | 9.74 | 3.0 | 11.3 | 0.58 | 4.8 | 40.8 | 2.23 | 15.2 |
| 5.0-8.9 | -- | -- | -- | .9 | .30 | 2.0 | 3.1 | .66 | 8.1 | 42.8 | 11.92 | 128.6 |
| 9.0-12.9 | .1 | .07 | .9 | .8 | .60 | 6.0 | .2 | .13 | 1.9 | 20.5 | 13.09 | 156.1 |
| 13.0-16.9 | -- | -- | -- | 1.0 | .69 | 11.6 | .1 | .07 | 1.0 | 8.6 | 10.42 | 123.0 |
| 17.0-20.9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3.9 | 7.44 | 80.4 |
| 21.0-24.9 | -- | -- | -- | -- | -- | -- | .1 | .07 | .8 | 1.5 | 4.18 | 44.0 |
| 25.0-28.9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .6 | 2.34 | 20.1 |
| 29.0-32.9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | .1 | .72 | 4.8 |
| 33.0+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total | 3.9 | .20 | 1.6 | 16.0 | 11.33 | 22.6 | 14.8 | 1.51 | 16.6 | 118.8 | 52.34 | 572.2 |

[1]As measured on 154 sample points, upper zone, and 84 sample points, lower zone.

Table 23. — Number of trees, volume, and growth per acre of singleleaf pinyon and Utah juniper (species combined) in the woodland type in western Nevada (Reveal 1944)

| Stand maturity class | Crown density class | Trees | Cubic volume | Decadal growth |
|---|---|---|---|---|
| | Percent | Number | Cubic feet | |
| Immature | 1-10 | 52 | 73 | 28 |
| | 11-20 | 120 | 168 | 66 |
| | 21-40 | 174 | 322 | 139 |
| | 41-60 | 216 | 421 | 183 |
| Mature | 1-10 | 49 | 105 | 43 |
| | 11-20 | 128 | 326 | 122 |
| | 21-40 | 154 | 616 | 182 |
| | 41-60 | 314 | 801 | 298 |
| Overmature | 1-10 | 53 | 164 | 52 |
| | 11-20 | 92 | 717 | 106 |
| | 21-40 | 182 | 1,110 | 236 |
| | 41-60 | 380 | 1,440 | 456 |

Table 24. — Some tree characteristics of singleleaf pinyon and Utah juniper in the woodland type in western Nevada (Reveal 1944)

| Diameter, breast high[1] (Inches) | Sample trees | Average tree height[1] | Average crown width | Average age | Average diameter growth per decade | Average volume[2] |
|---|---|---|---|---|---|---|
| | Number | Feet | Feet | Years | Inches | Cu. ft. |
| | | SINGLELEAF PINYON | | | | |
| 3 | 10 | 11.5 | 10.0 | 43 | 1.02 | 0.6 |
| 4 | 13 | 12.7 | 11.5 | 52 | .99 | 1.1 |
| 5 | 13 | 14.2 | 13.0 | 62 | .95 | 1.6 |
| 6 | 19 | 15.6 | 14.3 | 73 | .90 | 2.6 |
| 7 | 9 | 17.0 | 15.6 | 84 | .85 | 4.0 |
| 8 | 14 | 18.4 | 16.8 | 96 | .79 | 5.7 |
| 9 | 6 | 19.7 | 17.5 | 109 | .74 | 7.5 |
| 10 | 6 | 21.0 | 17.8 | 123 | .68 | 9.0 |
| 12 | 3 | 23.2 | 18.2 | 155 | .54 | 11.8 |
| 14 | 1 | 25.2 | 18.5 | -- | .40 | 14.0 |
| | | UTAH JUNIPER | | | | |
| 3 | 10 | 10.5 | 10.0 | -- | -- | -- |
| 4 | 5 | 12.0 | 11.5 | -- | -- | -- |
| 5 | 11 | 13.0 | 13.0 | -- | -- | -- |
| 6 | 5 | 14.0 | 14.5 | -- | -- | -- |
| 7 | 4 | 15.0 | 16.0 | -- | -- | -- |
| 8 | 1 | 16.0 | 17.3 | -- | -- | -- |
| 9 | 1 | 16.8 | 18.4 | -- | -- | -- |
| 10 | 1 | 17.6 | 19.5 | -- | -- | -- |
| 12 | 3 | 19.0 | 21.5 | -- | -- | -- |
| 14 | 2 | 20.2 | 23.0 | -- | -- | -- |

[1] Measured on the largest stem of multiple-stem trees; tree height measured on same stem.
[2] Total cubic-foot volume of all 4-foot stem and limb sections 2 inches or more in mid-diameter: volume computed by Huber's formula.

Table 25. — Average 20-year growth of Utah juniper in central Arizona (Myers 1962)

| Diameter, stump high (Inches) | 1938 stand | | Average growth per stem, 1938-58 | | |
|---|---|---|---|---|---|
| | Trees measured | Average height | Diameter stump high | Total height | Volume |
| | Number | Feet | Inches | Feet | Cu. ft. |
| 4-6 | 76 | 12.1 | 1.20 | 1.01 | 0.81 |
| 7-10 | 56 | 15.3 | .99 | .36 | 1.06 |
| 11-14 | 40 | 18.3 | .95 | 1.04 | 1.21 |
| 15-18 | 23 | 21.4 | .66 | .68 | .71 |
| 19-22 | 15 | 22.3 | 1.02 | -1.07 | .94 |
| 23-26 | 7 | 23.6 | .89 | -.73 | .87 |
| 31-32 | 2 | 28.5 | 1.95 | -1.55 | 2.54 |

Table 26. — Growth characteristics of pinyon and juniper trees in the pinyon-juniper woodland type in northern Arizona and New Mexico (adapted from Howell 1940, tables 8 and 10)

| Diameter, stump high (Inches) | Pinyon | | | | Juniper | | | |
|---|---|---|---|---|---|---|---|---|
| | Average age | Average height | Average volume | 10-year diameter growth | Average age | Average height | Average volume | 10-year diameter growth |
| | Years | Feet | Cu. ft. | Inches | Years | Feet | Cu. ft. | Inches |
| 1 | 24 | 5.2 | -- | 0.50 | 28 | 3.8 | -- | 0.50 |
| 2 | 42 | 8.3 | -- | .63 | 49 | 8.6 | -- | .53 |
| 3 | 58 | 10.5 | 0.24 | .69 | 68 | 11.6 | 0.23 | .57 |
| 4 | 73 | 13.0 | .53 | .68 | 87 | 12.3 | .65 | .58 |
| 5 | 86 | 14.6 | .85 | .64 | 104 | 12.6 | 1.13 | .56 |
| 6 | 100 | 16.7 | 1.47 | .61 | 121 | 13.0 | 1.60 | .54 |
| 7 | 112 | 18.4 | 2.24 | .59 | 139 | 13.6 | 2.12 | .52 |
| 8 | 127 | 20.0 | 3.35 | .56 | 154 | 14.0 | 2.74 | .50 |
| 9 | 143 | 21.9 | 5.20 | .54 | 170 | 14.7 | 3.55 | .48 |
| 10 | 160 | 23.4 | 7.50 | .52 | 185 | 15.3 | 4.46 | .47 |
| 11 | 176 | 25.0 | 10.00 | .51 | 200 | 15.8 | 5.50 | .47 |
| 12 | 191 | 26.0 | 12.85 | .50 | 214 | 16.4 | 7.22 | .46 |
| 13 | 203 | 27.2 | 15.28 | .48 | 229 | 17.0 | 8.95 | .46 |
| 14 | 216 | 28.0 | 18.00 | .46 | 241 | 17.8 | 10.95 | .46 |
| 15 | 229 | 29.0 | 21.15 | .45 | 255 | 18.7 | 13.00 | .46 |
| 16 | 240 | 29.7 | 23.75 | .43 | 267 | 19.3 | 15.50 | .45 |
| 17 | 251 | 30.3 | 26.00 | .43 | 280 | 20.0 | 18.25 | .45 |
| 18 | 261 | 30.8 | 28.35 | .44 | 292 | 20.8 | 21.10 | .45 |
| 19 | 272 | 31.6 | 31.40 | .45 | 303 | 21.7 | 24.00 | .45 |
| 20 | 283 | 32.0 | 34.25 | .46 | 317 | 22.4 | 27.50 | .44 |
| 21 | 293 | 32.7 | 37.40 | .50 | 325 | 23.1 | 31.00 | .44 |
| 22 | 303 | 33.4 | 40.00 | -- | 340 | 24.0 | 35.00 | .43 |
| 23 | 312 | 33.9 | 43.50 | -- | 350 | 25.0 | 39.40 | .43 |
| 24 | 321 | 34.7 | 47.20 | -- | 360 | 25.8 | 44.00 | .43 |
| 25 | 330 | 35.5 | 50.85 | -- | 368 | 26.7 | 48.25 | .43 |
| 26 | 339 | 36.0 | 53.75 | -- | 378 | 27.5 | 53.10 | -- |
| 27 | 348 | 36.8 | 58.40 | -- | 386 | 28.3 | 58.80 | -- |
| 28 | 357 | 37.5 | 62.80 | -- | 400 | 29.4 | 65.00 | -- |
| 29 | -- | -- | -- | -- | 408 | 30.2 | 70.00 | -- |
| 30 | -- | -- | -- | -- | 418 | 31.3 | 77.00 | -- |
| 31 | -- | -- | -- | -- | 425 | 32.2 | 82.50 | -- |
| 32 | -- | -- | -- | -- | 437 | 33.4 | 90.00 | -- |
| 33 | -- | -- | -- | -- | 444 | 34.0 | 95.25 | -- |
| 34 | -- | -- | -- | -- | 453 | 35.0 | 103.50 | -- |
| 35 | -- | -- | -- | -- | 460 | 36.0 | 113.00 | -- |
| 36 | -- | -- | -- | -- | 467 | 36.9 | 119.20 | -- |

Table 27. — Gross growth of pinyon and juniper species per acre per year, in the pinyon-juniper woodland type in northern Arizona and New Mexico (adapted from Howell 1940, table 33)

| Diameter, stump high (Inches) | Gross growth | | |
|---|---|---|---|
| | Pinyon | Juniper | Both species |
| | Cubic feet | | |
| 3 | 0.18 | 0.38 | 0.56 |
| 4 | .51 | .32 | .83 |
| 5 | .39 | .28 | .67 |
| 6 | .56 | .21 | .77 |
| 7 | .60 | .21 | .81 |
| 8 | .59 | .19 | .78 |
| 9 | .56 | .19 | .75 |
| 10 | .51 | .15 | .66 |
| 11 | .42 | .19 | .61 |
| 12 | .35 | .18 | .53 |
| 13 | .31 | .18 | .49 |
| 14 | .24 | .15 | .39 |
| 15 | .18 | .14 | .32 |
| 16 | .14 | .12 | .26 |
| 17 | .10 | .11 | .21 |
| 18 | .07 | .09 | .16 |
| 19 | .06 | .08 | .14 |
| 20 | .04 | .06 | .10 |
| 21 | .03 | .06 | .09 |
| 22 | .03 | .04 | .07 |
| 23 | .02 | .03 | .05 |
| 24 | .02 | .04 | .06 |
| 25 | .01 | .03 | .04 |
| 26 | .01 | .02 | .03 |
| 27 | .01 | .02 | .03 |
| 28 | .01 | .01 | .02 |
| 29 | -- | .01 | .01 |
| 30 | -- | .01 | .01 |
| 31 | -- | .01 | .01 |
| 32 | -- | .01 | .01 |
| 33 | -- | .01 | .01 |
| 34 | -- | .01 | .01 |
| 35 | -- | .01 | .01 |
| 36 | -- | .01 | .01 |
| Total | 5.95 | 3.56 | 9.51 |

Table 28. — Number of trees, basal area, and volume per acre of alligator juniper and Gambel oak, by zones[1]

| Diameter, breast high (inches) | Alligator juniper | | | | | | Gambel oak | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper woodland zone, below Mogollon Rim | | | Ponderosa pine type, lower | | | Ponderosa pine type -- Upper | | | Ponderosa pine type -- Lower | | |
| | Trees | Basal area | Volume | Trees | Basal area | Volume | Trees | Basal area | Volume | Trees | Basal area | Volume |
| | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. | No. | Sq. ft. | Cu. ft. |
| 0.1-4.9 | 92.87 | 3.84 | 28.7 | 30.80 | 1.07 | 6.8 | 34.32 | 1.11 | 5.6 | 55.80 | 1.62 | 8.0 |
| 5.0-8.9 | 10.76 | 2.70 | 35.3 | 1.79 | .45 | 6.0 | 9.44 | 2.47 | 21.5 | 6.66 | 1.74 | 15.1 |
| 9.0-12.9 | 2.04 | 1.24 | 18.3 | .48 | .31 | 4.7 | 5.55 | 3.82 | 49.1 | 7.11 | 4.27 | 51.4 |
| 13.0-16.9 | .83 | 1.34 | 15.3 | .54 | .69 | 10.0 | 3.23 | 3.82 | 60.6 | 3.24 | 3.62 | 55.9 |
| 17.0-20.9 | .32 | .66 | 8.5 | .35 | .71 | 9.2 | 2.19 | 4.21 | 80.0 | 1.16 | 2.30 | 44.0 |
| 21.0-24.9 | .34 | .97 | 11.6 | .16 | .45 | 5.4 | .80 | 2.24 | 48.1 | .35 | .97 | 20.8 |
| 25.0-28.9 | .19 | .76 | 8.0 | .45 | 1.81 | 18.9 | .20 | .78 | 18.8 | -- | -- | -- |
| 29.0-32.9 | .10 | .55 | 4.6 | .12 | .63 | 5.6 | -- | -- | -- | -- | -- | -- |
| 33.0-36.9 | .16 | 1.08 | 8.3 | .26 | 1.74 | 13.4 | .03 | .21 | 5.7 | -- | -- | -- |
| 37.0-40.9 | .08 | .70 | 4.6 | .19 | 1.52 | 10.4 | -- | -- | -- | -- | -- | -- |
| 41.0-44.9 | .05 | .53 | 2.9 | .09 | .92 | 5.2 | -- | -- | -- | -- | -- | -- |
| 45.0-48.9 | .03 | .44 | 2.0 | .13 | 1.61 | 7.8 | -- | -- | -- | -- | -- | -- |
| 49.0-52.9 | .03 | .41 | 1.8 | .10 | 1.36 | 6.0 | -- | -- | -- | -- | -- | -- |
| 53.0+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total | 107.80 | 15.22 | 149.9 | 35.46 | 13.27 | 109.4 | 55.76 | 18.66 | 289.4 | 74.32 | 14.52 | 195.2 |

[1]Alligator juniper measured on 154 sample points, upper woodland zone, and 200 points, ponderosa pine type; Gambel oak measured on 124 sample points, upper ponderosa pine type, and 76, lower ponderosa pine type.

Table 29. — Some tree characteristics of alligator juniper and Gambel oak in central Arizona

| Diameter, breast high (inches) | Alligator juniper[1] | | | Gambel oak[1] | | |
|---|---|---|---|---|---|---|
| | Average height | Average diameter growth per decade | Average volume | Average height | Average diameter growth per decade | Average volume |
| | Feet | Inches | Cu.ft. | Feet | Inches | Cu.ft. |
| 2 | 8 | 0.70 | 0.1 | 7 | 0.62 | 0.1 |
| 4 | 10 | .69 | .8 | 12 | .61 | .5 |
| 6 | 12 | .68 | 2.3 | 17 | .60 | 1.6 |
| 8 | 14 | .66 | 5.0 | 22 | .59 | 3.2 |
| 10 | 16 | .65 | 8.0 | 27 | .58 | 6.2 |
| 12 | 18 | .64 | 11.9 | 32 | .57 | 10.6 |
| 14 | 19 | .63 | 16.0 | 36 | .56 | 16.2 |
| 16 | 20 | .62 | 20.3 | 40 | .55 | 23.4 |
| 18 | 22 | .61 | 25.1 | 44 | .55 | 32.6 |
| 20 | 23 | .60 | 27.5 | 47 | .54 | 43.0 |
| 22 | 24 | .59 | 32.5 | 50 | .53 | 55.4 |
| 24 | 25 | .58 | 36.2 | 53 | .52 | 70.0 |
| 26 | 26 | .57 | 40.2 | 56 | .52 | 86.8 |
| 28 | 27 | .56 | 43.3 | 58 | .51 | 103.0 |
| 30 | 27 | .55 | 45.8 | 60 | .50 | 124.0 |
| 32 | 28 | .54 | 48.7 | 62 | .50 | 146.0 |
| 34 | 28 | .53 | 50.8 | 63 | .49 | 167.0 |
| 36 | — | — | — | 64 | .49 | 190.0 |

[1]Regression values based on 73 sample alligator juniper trees, and 134 sample Gambel oak trees.

Table 30. — Gross cubic-foot volume[1] of Utah and alligator juniper trees (modification and extension of tables by Howell and Lexen 1939)

| Diameter, breast high (inches) | Total height (feet) of — — | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Utah juniper | | | | | Alligator juniper | | | | |
| | 10 | 15 | 20 | 25 | 30 | 10 | 15 | 20 | 25 | 30 |
| | Cubic feet | | | | | | | | | |
| 2 | 0.1 | 0.1 | 0.1 | | | 0.1 | 0.2 | 0.2 | | |
| 4 | .5 | .5 | .5 | 0.5 | | .8 | .8 | .8 | 0.8 | |
| 6 | 1.5 | 1.6 | 1.7 | 1.7 | 1.8 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 |
| 8 | 3.3 | 3.4 | 3.4 | 3.5 | 3.6 | 4.9 | 5.0 | 5.1 | 5.2 | 5.3 |
| 10 | 5.2 | 5.4 | 5.5 | 5.6 | 5.6 | 7.8 | 8.0 | 8.2 | 8.3 | 8.4 |
| 12 | | 7.9 | 8.0 | 8.0 | 8.2 | | 11.8 | 11.9 | 12.0 | 12.2 |
| 14 | | 10.6 | 10.7 | 10.8 | 10.8 | | 15.8 | 16.0 | 16.1 | 16.2 |
| 16 | | | 13.6 | 13.9 | 14.1 | | | 20.3 | 20.7 | 21.0 |
| 18 | | | 16.8 | 16.9 | 17.2 | | | 25.0 | 25.2 | 25.7 |
| 20 | | | 18.3 | 18.5 | 18.8 | | | 27.3 | 27.6 | 28.1 |
| 22 | | | 21.4 | 21.8 | 22.4 | | | 31.9 | 32.6 | 33.4 |
| 24 | | | | 24.5 | 24.8 | | | | 36.2 | 37.1 |
| 26 | | | | 26.8 | 27.3 | | | | 40.0 | 40.8 |
| 28 | | | | 28.7 | 29.3 | | | | 42.9 | 43.7 |
| 30 | | | | | | | | | 45.4 | 46.2 |
| 32 | | | | | | | | | 48.1 | 48.9 |
| 34 | | | | | | | | | 50.3 | 51.0 |
| 36 | | | | | | | | | 51.6 | 52.3 |
| 38 | | | | | | | | | | 54.1 |
| 40 | | | | | | | | | | 55.8 |
| 42 | | | | | | | | | | 57.0 |
| 44 | | | | | | | | | | 58.1 |
| 46 | | | | | | | | | | 59.1 |
| 48 | | | | | | | | | | 59.9 |
| 50 | | | | | | | | | | 60.2 |

[1]Cubic volume includes all pieces 4 feet long or longer with mid-diameter of 2 inches or more, excluding a 1-foot stump.

Table 31. — Gross cubic-foot volume[1] of pinyon trees (developed from data presented by Howell, 1940)

| Diameter, stump high (Inches) | Total height (feet) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| | Cubic feet | | | | | | |
| 4 | 0.6 | 0.7 | | | | | |
| 6 | 1.6 | 2.0 | 2.3 | | | | |
| 8 | 3.5 | 4.2 | 4.9 | 5.5 | | | |
| 10 | 5.5 | 6.6 | 7.7 | 8.8 | | | |
| 12 | | 8.0 | 9.6 | 11.2 | 12.7 | | |
| 14 | | 9.7 | 11.9 | 14.0 | 16.1 | | |
| 16 | | | 14.5 | 17.3 | 20.1 | 22.8 | |
| 18 | | | 17.4 | 21.0 | 24.5 | 28.0 | |
| 20 | | | 20.8 | 25.1 | 29.5 | 33.8 | |
| 22 | | | | 29.7 | 35.0 | 40.2 | 45.5 |
| 24 | | | | 34.7 | 41.0 | 47.3 | 53.5 |
| 26 | | | | 40.2 | 47.5 | 54.9 | 62.3 |
| 28 | | | | 46.0 | 54.6 | 63.1 | 71.7 |
| 30 | | | | | 62.2 | 72.0 | 81.8 |

[1]Cubic volume includes all pieces 4 feet long or longer with mid-diameter of 2 inches or more, excluding a 1-foot stump. Volume of trees 10 inches and larger in diameter derived from the equation $V = 3.315 + 0.0022 D^2H$.

Table 32. — Gross cubic-foot volume[1] of Gambel oak trees (adapted from Gevorkiantz and Olson 1955, table 3)

| Diameter, breast high (Inches) | Total height --- feet | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| | Cubic feet | | | | | | | |
| 3 | 0.5 | | | | | | | |
| 4 | .8 | | | | | | | |
| 5 | 1.3 | 1.7 | | | | | | |
| 6 | 1.9 | 2.5 | | | | | | |
| 7 | 2.6 | 3.4 | 4.5 | | | | | |
| 8 | 3.4 | 4.4 | 5.9 | | | | | |
| 9 | 4.3 | 5.6 | 7.4 | 9.3 | | | | |
| 10 | 5.3 | 6.9 | 9.2 | 11.4 | | | | |
| 11 | 6.4 | 8.3 | 11.1 | 13.9 | 16.6 | | | |
| 12 | 7.6 | 9.8 | 13.2 | 16.5 | 19.8 | | | |
| 13 | | 11.4 | 15.5 | 19.4 | 23.2 | | | |
| 14 | | 13.1 | 18.0 | 22.4 | 26.9 | | | |
| 15 | | 15.0 | 20.6 | 25.8 | 30.9 | | | |
| 16 | | 17.0 | 23.5 | 29.3 | 35.2 | 41.0 | | |
| 17 | | 19.1 | 26.5 | 33.1 | 39.7 | 46.3 | | |
| 18 | | 21.3 | 29.7 | 37.1 | 44.5 | 51.9 | | |
| 19 | | | 33.1 | 41.3 | 49.6 | 57.9 | | |
| 20 | | | 36.7 | 45.8 | 55.0 | 64.2 | | |
| 21 | | | 40.5 | 50.5 | 60.6 | 70.7 | 80.8 | |
| 22 | | | 44.5 | 55.4 | 66.5 | 77.6 | 88.7 | |
| 23 | | | 48.7 | 60.6 | 72.7 | 84.8 | 96.9 | |
| 24 | | | 53.1 | 66.0 | 79.2 | 92.4 | 106.0 | |
| 25 | | | | 71.6 | 85.9 | 100.0 | 115.0 | |
| 26 | | | | 77.5 | 93.0 | 108.0 | 124.0 | |
| 27 | | | | 83.6 | 100.0 | 117.0 | 134.0 | |
| 28 | | | | 89.9 | 108.0 | 126.0 | 144.0 | |
| 29 | | | | 96.4 | 116.0 | 135.0 | 154.0 | 174.0 |
| 30 | | | | 103.0 | 124.0 | 144.0 | 165.0 | 186.0 |

[1] Cubic volume includes peeled volume of entire stem.

Table 33. — Preliminary aerial volume table for the pinyon-juniper type: gross cubic volume per acre by average stand height, average crown diameter, and crown coverage (Moessner 1962)[1]

| Average stand height (Feet) | Crown cover (percent) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 |
| | Cubic feet | | | | | | | | | |
| | CROWN DIAMETER: 4 TO 7 (5) FEET | | | | | | | | | |
| 10 | 20 | 20 | 20 | 10 | 10 | 0 | | | | |
| 15 | 20 | 50 | 70 | 100 | 110 | 130 | 150 | 170 | 190 | 210 |
| 20 | | | | | | 140 | 180 | 220 | 260 | 300 |
| | CROWN DIAMETER: 8 TO 12 (10) FEET | | | | | | | | | |
| 10 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 10 | 10 |
| 15 | 120 | 150 | 170 | 200 | 220 | 250 | 270 | 290 | 310 | 330 |
| 20 | 120 | 160 | 210 | 260 | 310 | 350 | 400 | 440 | 490 | 530 |
| 25 | | | | | | | 410 | 480 | 540 | 610 |
| | CROWN DIAMETER: 13 TO 17 (15) FEET | | | | | | | | | |
| 15 | 130 | 160 | 190 | 210 | 240 | 260 | 290 | 320 | 340 | 360 |
| 20 | 220 | 280 | 330 | 380 | 430 | 480 | 520 | 570 | 620 | 670 |
| 25 | | 280 | 350 | 420 | 490 | 560 | 640 | 710 | 780 | 850 |
| 30 | | | | | | | | 730 | 820 | 910 |
| | CROWN DIAMETER: 18 TO 22 (20) FEET | | | | | | | | | |
| 15 | 50 | 80 | 110 | 140 | 170 | 190 | 220 | 250 | 270 | 300 |
| 20 | 240 | 300 | 350 | 400 | 450 | 510 | 560 | 610 | 660 | 710 |
| 25 | 320 | 390 | 470 | 550 | 620 | 700 | 770 | 850 | 920 | 990 |
| 30 | | | 470 | 570 | 670 | 770 | 870 | 970 | 1,070 | 1,160 |
| 35 | | | | | | | | 970 | 1,090 | 1,210 |

[1]Figures in blocked areas are based on field data. Average stand heights, crown diameters, and cubic volume were obtained from field measurements, and crown cover was obtained from photo measurements of field plots. Measurements obtained on 48 Forest Survey field plots randomly located in Utah.
Aggregate deviation: table -0.17 percent low.
Standard error of estimate: ±60 percent of mean plot volume.

# APPENDIX C

## PHYSICAL PROPERTIES

Table 34. — Specific gravity, based on ovendry weight and green volume, of unextracted and extracted increment cores from four woodland species

| Size, by diameter or stem-form class | Trees | Unextracted cores | | | | Extracted cores | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | 95% C.I. | Maximum | Minimum | Mean | 95% C.I. |
| | No. | | | | | | | | |
| | | | | | PINYON | | | | |
| Diameter Class: | | | | | | | | | |
| Saplings and poles (2.0-6.9 inches) | 16 | 0.573 | 0.476 | 0.521 | ±0.014 | 0.546 | 0.438 | 0.499 | ±0.014 |
| Large poles (7.0-10.9 inches) | 13 | .624 | .446 | .505 | ±.028 | .580 | .423 | .483 | ±.026 |
| Sawtimber (11.0+ inches) | 9 | .533 | .430 | .476 | ±.027 | .513 | .405 | .457 | ±.026 |
| All classes | 38 | .624 | .430 | .506 | ±.013 | .580 | .405 | .484 | ±.012 |
| | | | | | UTAH JUNIPER | | | | |
| Diameter Class: | | | | | | | | | |
| 0-10.9 inches | 14 | .682 | .477 | .548 | ±.033 | .605 | .454 | .487 | ±.023 |
| 11-20.9 inches | 18 | .549 | .439 | .489 | ±.014 | .500 | .390 | .455 | ±.015 |
| 21+ inches | 10 | .558 | .439 | .498 | ±.029 | .509 | .400 | .457 | ±.026 |
| Stem-form Class: | | | | | | | | | |
| Single stem | 18 | .605 | .439 | .505 | ±.023 | .512 | .390 | .458 | ±.015 |
| Fork between ground line and breast height | 8 | .558 | .439 | .492 | ±.034 | .500 | .400 | .459 | ±.030 |
| Fork at ground line | 16 | .682 | .472 | .527 | ±.029 | .605 | .412 | .481 | ±.022 |
| All classes | 42 | .682 | .439 | .511 | ±.015 | .605 | .390 | .466 | ±.012 |

*continued*

Table 34. — Specific gravity, based on ovendry weight and green volume, of unextracted and extracted increment cores from four woodland species -- *continued*

| Size, by diameter or stem-form class | Trees | Unextracted cores | | | | Extracted cores | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | 95% C.I. | Maximum | Minimum | Mean | 95% C.I. |
| | No. | | | | | | | | |
| | | | | ALLIGATOR JUNIPER[1] | | | | | |
| Diameter Class: | | | | | | | | | |
| 0-10.9 inches | 9 | .533 | .478 | .495 | ±.013 | .486 | .426 | .458 | ±.014 |
| 11-20.9 inches | 8 | .471 | .372 | .440 | ±.027 | .445 | .356 | .418 | ±.023 |
| 21-40.9 inches | 20 | .497 | .398 | .442 | ±.012 | .448 | .369 | .415 | ±.010 |
| 41+ inches | 9 | .497 | .399 | .446 | ±.023 | .470 | .375 | .425 | ±.030 |
| Stem-form Class: | | | | | | | | | |
| Single stem | 23 | .508 | .372 | .458 | ±.015 | .480 | .356 | .427 | ±.009 |
| Fork between ground line and breast height | 17 | .497 | .398 | .442 | ±.013 | .470 | .375 | .418 | ±.012 |
| Fork at ground line | 6 | .533 | .426 | .465 | ±.040 | .486 | .400 | .442 | ±.038 |
| All classes | 46 | .533 | .372 | .453 | ±.010 | .486 | .356 | .426 | ±.008 |
| | | | | GAMBEL OAK[1] | | | | | |
| Diameter Class: | | | | | | | | | |
| Saplings and poles (2.0-6.9 inches) | 15 | .706 | .596 | .653 | ±.022 | .672 | .531 | .598 | ±.028 |
| Large poles (7.0-10.9 inches) | 20 | .693 | .569 | .624 | ±.015 | .619 | .509 | .557 | ±.018 |
| Sawtimber (11.0+ inches) | 13 | .696 | .572 | .625 | ±.024 | .585 | .495 | .539 | ±.025 |
| All classes | 48 | .706 | .569 | .634 | ±.010 | .672 | .495 | .567 | ±.015 |

[1] Unextracted specific gravity data for alligator or juniper from Barger and Ffolliott (1965); for Gambel oak, from Barger and Ffolliott (1964).

Table 35. — Strength properties of selected woodland species woods, based on tests of sample material (Markwardt and Wilson 1935)

| Property | Unit of measure | Species and moisture condition | | | | | | Probable variation from average[2] | Effect of moisture content change[3] |
|---|---|---|---|---|---|---|---|---|---|
| | | Pinyon | | Alligator juniper | | Gambel oak | | | |
| | | Green | Air-dry[1] | Green | Air-dry[1] | Green | Air-dry[1] | | |
| | | | | | | | | -- Percent -- | |
| Static bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 2,600 | 5,600 | 3,600 | 5,400 | 3,200 | 5,200 | 9 | 5.0 |
| Modulus of rupture | Lb./sq.in. | 4,800 | 7,800 | 6,600 | 6,700 | 5,900 | 8,500 | 7 | 4.0 |
| Modulus of elasticity | M lb./sq. in. | 650 | 1,140 | 450 | 650 | 480 | 680 | 9 | 2.0 |
| Work to proportional limit | In.-lb./cu.in. | .61 | 1.86 | 1.67 | 2.74 | 1.23 | 2.30 | — | 8.0 |
| Work to maximum load | In.-lb./cu.in. | 7.6 | 4.7 | 13.4 | 6.5 | 11.3 | 9.0 | 15 | .5 |
| Total work | In.-lb./cu.in. | 23.0 | 6.1 | 16.4 | — | 27.2 | 13.3 | — | — |
| Impact bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 8,200 | 8,500 | 6,800 | 5,600 | 8,100 | 14,100 | 8 | 3.0 |
| Work to proportional limit | In.-lb./cu.in. | 4.2 | 3.0 | 3.9 | 2.5 | 4.3 | 5.2 | 12 | 4.0 |
| Height drop (50-lb. hammer) causing failure | In. | 21 | 12 | 21 | 12 | 80 | 23 | 13 | -.5 |
| Compression parallel to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 1,810 | — | 2,490 | — | 1,330 | — | 12 | 5.0 |
| Maximum crushing strength | Lb./sq.in. | 2,590 | 6,400 | 3,730 | 4,120 | 2,940 | 5,200 | 7 | 6.0 |
| Compression perpendicular to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 480 | 1,520 | 1,030 | 1,700 | 1,110 | 2,070 | 14 | 5.5 |
| Hardness: | | | | | | | | | |
| End | Lb. | 510 | 920 | 960 | 1,290 | 1,210 | 2,030 | 10 | 4.0 |
| Side | Lb. | 600 | 860 | 820 | 1,160 | 1,280 | 1,440 | 9 | 2.5 |
| Shear parallel to grain: (maximum shearing strength) | Lb./sq.in. | 920 | — | 1,280 | — | 1,530 | — | 7 | 3.0 |
| Cleavage: (load to cause splitting) | Lb./in. of width | — | — | — | — | 370 | — | — | — |
| Tension perpendicular to grain: (maximum tensile strength) | Lb./sq.in. | 460 | — | — | — | 750 | — | 12 | 1.5 |

[1] All values shown for wood in air-dry condition are adjusted to a uniform 12 percent moisture content.
[2] Probable variation values are averages derived from a number of species.
[3] Average increase or decrease in strength associated with a 1 percent reduction in moisture content.

Table 36. — Calculated strength properties of the woodland species woods, based on specific gravity[1]

| Property | Unit of measure | Pinyon Green | Pinyon Air-dry | Utah juniper Green | Utah juniper Air-dry | Alligator juniper Green | Alligator juniper Air-dry | Gambel oak Green | Gambel oak Air-dry |
|---|---|---|---|---|---|---|---|---|---|
| | | | | UNEXTRACTED SPECIFIC GRAVITY | | | | | |
| Static bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 4,350 | 7,550 | 4,410 | 7,550 | 3,800 | 6,510 | 5,830 | 10,270 |
| Modulus of rupture | Lb./sq.in. | 7,510 | 11,620 | 7,600 | 11,620 | 6,560 | 10,020 | 10,060 | 15,810 |
| Modulus of elasticity | M lb./sq. in. | 1,190 | 1,490 | 1,210 | 1,490 | 1,070 | 1,320 | 1,510 | 1,900 |
| Work to maximum load | In.-lb./cu.in. | 10.8 | 10.7 | 11.0 | 10.7 | 8.9 | 8.7 | 16.3 | 16.4 |
| Total work | In.-lb./cu.in. | 26.4 | 20.5 | 26.9 | 20.5 | 21.2 | 16.1 | 42.0 | 33.4 |
| Impact bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 10,110 | 14,100 | 10,240 | 14,100 | 8,830 | 12,170 | 13,540 | 19,190 |
| Modulus of elasticity | M lb./sq. in. | 1,490 | 1,790 | 1,500 | 1,790 | 1,330 | 1,590 | 1,880 | 2,290 |
| Height drop (50-lb. hammer) causing failure | In. | 35 | 31 | 35 | 31 | 29 | 25 | 52 | 48 |
| Compression parallel to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 2,660 | 4,650 | 2,680 | 4,650 | 2,380 | 4,120 | 3,350 | 5,930 |
| Maximum crushing strength | Lb./sq.in. | 3,410 | 6,480 | 3,440 | 6,480 | 3,060 | 5,750 | 4,300 | 8,270 |
| Compression perpendicular to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 650 | 1,110 | 660 | 1,110 | 510 | 850 | 1,090 | 1,930 |
| Hardness: | | | | | | | | | |
| End | Lb. | 808 | 1,150 | 826 | 1,150 | 633 | 880 | 1,365 | 2,000 |
| Side | Lb. | 739 | 900 | 755 | 900 | 579 | 690 | 1,249 | 1,570 |
| | | | | EXTRACTED SPECIFIC GRAVITY | | | | | |
| Static bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 4,120 | 7,160 | 3,930 | 6,760 | 3,510 | 6,030 | 5,020 | 8,950 |
| Modulus of rupture | Lb./sq.in. | 7,110 | 11,030 | 6,780 | 10,410 | 6,060 | 9,280 | 8,660 | 13,780 |
| Modulus of elasticity | M lb./sq. in. | 1,140 | 1,420 | 1,100 | 1,360 | 1,010 | 1,240 | 1,340 | 1,700 |
| Work to maximum load | In.-lb./cu.in. | 10.0 | 9.9 | 9.4 | 9.1 | 8.0 | 7.8 | 13.2 | 13.5 |
| Total work | In.-lb./cu.in. | 24.1 | 18.8 | 22.4 | 17.1 | 18.7 | 14.2 | 33.1 | 26.8 |
| Impact bending: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 9,570 | 13,380 | 9,120 | 12,640 | 8,160 | 11,260 | 11,660 | 16,720 |
| Modulus of elasticity | M lb./sq. in. | 1,420 | 1,720 | 1,370 | 1,640 | 1,250 | 1,500 | 1,670 | 2,050 |
| Height drop (50-lb. hammer) causing failure | In. | 32 | 29 | 30 | 27 | 26 | 23 | 42 | 39 |
| Compression parallel to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 2,540 | 4,450 | 2,450 | 4,240 | 2,240 | 3,880 | 2,980 | 5,310 |
| Maximum crushing strength | Lb./sq.in. | 3,260 | 6,200 | 3,140 | 5,920 | 2,870 | 5,400 | 3,820 | 7,410 |
| Compression perpendicular to grain: | | | | | | | | | |
| Fiber stress at proportional limit | Lb./sq.in. | 590 | 1,010 | 540 | 910 | 440 | 740 | 840 | 1,500 |
| Hardness: | | | | | | | | | |
| End | Lb. | 731 | 1,050 | 671 | 940 | 548 | 770 | 1,043 | 1,560 |
| Side | Lb. | 668 | 820 | 614 | 740 | 501 | 600 | 954 | 1,230 |

[1]Based on empirical equations developed by the Forest Products Laboratory relating specific gravity to strength (Markwardt 1930, U.S. Forest Service 1956).

# APPENDIX D

## WOOD PRODUCT UTILIZATION

Table 37. — Minimum property requirements of interior and exterior types of mat-formed wood particleboard (U. S. Department of Commerce 1966)

| Density[1] and class | Modulus of rupture | Modulus of elasticity | Internal bond | Linear expansion |
|---|---|---|---|---|
| | Lb./sq.in. | M lb./sq. in. | Lb./sq.in. | Percent |
| | | INTERIOR | | |
| High density: | | | | |
| Class 1 | 2,400 | 350 | 200 | 0.55 |
| Class 2 | 3,400 | 350 | 140 | .55 |
| Medium density: | | | | |
| Class 1 | 1,600 | 250 | 70 | .35 |
| Class 2 | 2,400 | 400 | 60 | .30 |
| Low density: | | | | |
| Class 1 | 800 | 150 | 20 | .30 |
| Class 2 | 1,400 | 250 | 30 | .30 |
| | | EXTERIOR | | |
| High density: | | | | |
| Class 1 | 2,400 | 350 | 125 | .55 |
| Class 2 | 3,400 | 500 | 400 | .55 |
| Medium density: | | | | |
| Class 1 | 1,800 | 250 | 65 | .35 |
| Class 2 | 2,500 | 450 | 60 | .25 |

[1] High, 50 lb./cu.ft. and over; medium, 37-50; low, under 37.

Table 38. — Average cord volume per tree and cordwood yield per acre in the pinyon-juniper woodland type in northern Arizona and New Mexico[1] (adapted from Howell 1940)

| Diameter, stump high (inches) | Average tree volume | | Average volume yield/acre | | |
|---|---|---|---|---|---|
| | Pinyon | Juniper | Pinyon | Juniper | Total |
| | Cords | | | | |
| 6 | 0.02 | 0.02 | 0.31 | 0.19 | 0.50 |
| 7 | .03 | .03 | .39 | .22 | .61 |
| 8 | .05 | .04 | .46 | .23 | .69 |
| 9 | .08 | .05 | .49 | .25 | .74 |
| 10 | .11 | .07 | .54 | .23 | .77 |
| 11 | .15 | .08 | .52 | .32 | .84 |
| 12 | .19 | .11 | .47 | .31 | .78 |
| 13 | .23 | .14 | .47 | .31 | .78 |
| 14 | .27 | .17 | .40 | .30 | .70 |
| 15 | .32 | .20 | .33 | .28 | .61 |
| 16 | .35 | .24 | .26 | .26 | .52 |
| 17 | .39 | .28 | .22 | .25 | .47 |
| 18 | .42 | .32 | .16 | .20 | .36 |
| 19 | .47 | .37 | .12 | .20 | .32 |
| 20 | .51 | .42 | .08 | .19 | .27 |
| 21 | .56 | .48 | .06 | .19 | .25 |
| 22 | .60 | .54 | .06 | .16 | .22 |
| 23 | .65 | .61 | .03 | .14 | .17 |
| 24 | .70 | .68 | .03 | .16 | .19 |
| 25 | .76 | .74 | .02 | .14 | .16 |
| 26 | .80 | .81 | .02 | .09 | .11 |
| 27 | .87 | .90 | .02 | .09 | .11 |
| 28 | .94 | 1.00 | .02 | .05 | .07 |
| 29 | — | 1.08 | — | .05 | .05 |
| 30 | — | 1.18 | — | .05 | .05 |
| 31 | — | 1.27 | — | .05 | .05 |
| 32 | — | 1.38 | — | .03 | .03 |
| 33 | — | 1.47 | — | .03 | .03 |
| 34 | — | 1.50 | — | .03 | .03 |
| 35 | — | 1.74 | — | .03 | .03 |
| 36 | — | 1.83 | — | .03 | .03 |
| Total | — | — | 5.48 | 5.06 | 10.54 |

[1] Cord measure based on solid wood content per cord averaging 67 cubic feet for pinyon and 65 cubic feet for juniper.

Table 39. — Service record of untreated fenceposts of selected southwestern tree species, by climatic zone (forested plateau and desert), at six locations in Arizona and New Mexico

| Species and climatic zone | Posts set | | Posts serviceable | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1940 | 1941 | 1945 | 1950 | 1958 | 1965 |
| | No. | Date | Percent | | | | | |
| Utah juniper | | | | | | | | |
| Forest | 15 | 1938 | 100 | 100 | 100 | 93 | 80 | 80 |
| Desert | 15 | 1939 | 100 | 100 | 100 | 100 | 100 | 100 |
| One-seed juniper | | | | | | | | |
| Forest | 15 | 1938 | 100 | 100 | 100 | 100 | 100 | 100 |
| Desert | 15 | 1939 | 100 | 100 | 100 | 100 | 100 | 100 |
| Alligator juniper | | | | | | | | |
| Forest | 15 | 1938 | 100 | 100 | 100 | 100 | 100 | 93 |
| Rocky Mountain juniper | | | | | | | | |
| Forest | 15 | 1938 | 100 | 100 | 100 | 100 | 93 | 80 |
| Desert | 15 | 1939 | 100 | 100 | 100 | 93 | 93 | 93 |
| Ponderosa pine | | | | | | | | |
| Forest | 5 | 1939 | 100 | 100 | 0 | 0 | 0 | 0 |
| Desert | 40 | 1940 | 100 | 100 | 0 | 0 | 0 | 0 |
| Pinyon | | | | | | | | |
| Forest | 5 | 1939 | 100 | 100 | 80 | 0 | 0 | 0 |
| Desert | 5 | 1940 | 100 | 100 | 0 | 0 | 0 | 0 |
| Gambel oak | | | | | | | | |
| Forest | 5 | 1939 | 100 | 100 | 100 | 100 | 80 | 20 |
| Desert | 29 | 1940 | 100 | 100 | 100 | 97 | 66 | 10 |

Table 40. — Estimated investment costs in sheet metal and masonry block kiln lump charcoal plants capable of producing 7 to 10 tons of charcoal per week

| Investment cost item | Estimated cost range per plant | |
|---|---|---|
| | Sheet metal[1] | Masonry block[2] |
| Kilns | \$2,800- 4,200 | \$4,000- 5,000 |
| Wood truck | 1,500- 2,500 | 1,500- 2,000 |
| Delivery truck | 2,500- 3,500 | 2,500- 3,000 |
| Chain saws | 400- 600 | 200- 300 |
| Camp cut-up saw | 200- 250 | 175- 200 |
| Axes, stones, etc. | 40- 50 | 40- 50 |
| Camp storage facilities | — | 300- 500 |
| Water storage and piping | — | 500- 750 |
| Packaging chutes | 75- 100 | 50- 75 |
| Scales and miscellaneous equipment | 300- 600 | 100- 150 |
| Total | \$7,815-11,800 | \$9,365-12,025 |
| Operating capital (current payroll, wood supply, bags, etc.) | \$1,000- 1,500 | \$1,500- 2,000 |

[1]Weekly capacity, 7 tons (Johnson 1965); seven 3-cord kilns, two chain saws.
[2]Weekly capacity, 10 tons (Kotok 1955); four 5-cord kilns; one chain saw.

Table 41. — Charcoal sold in the United States, by type of purchaser and region, 1961 (U.S. Forest Service 1963)

| Type of purchaser | North-east | South-east | Lake | Central | Southern | Cali-fornia | Other West | Total |
|---|---|---|---|---|---|---|---|---|
| | Tons | | | | | | | |
| Jobbers | 9,830 | 510 | 3,860 | 10,980 | 21,730 | 2,950 | 640 | 50,500 |
| Industrial users: | | | | | | | | |
| Metal | 3,900 | 3,690 | 210 | 3,620 | 770 | — | 30 | 12,220 |
| Chemical | 3,580 | 7,710 | 1,170 | 310 | 3,460 | — | — | 16,230 |
| Other | 1,360 | — | 20 | 1,900 | 50 | — | 20 | 3,350 |
| Total | 8,840 | 11,400 | 1,400 | 5,830 | 4,280 | — | 50 | 31,800 |
| Briquetting plants | 1,260 | 10,430 | 6,910 | 57,660 | 12,700 | 750 | 60 | 89,770 |
| Other | 520 | 130 | 10 | 80 | 4,200 | 280 | 70 | 5,290 |
| Total | 20,450 | 22,470 | 12,180 | 74,550 | 42,910 | 3,980 | 820 | 177,360 |

Table 42. — Uses of charcoal (U.S. Forest Service 1961)

| | | |
|---|---|---|
| DOMESTIC AND SPECIALIZED FUELS: | | |
| Recreational | | Heating, foundry, and plumbing equipment |
| Curing tobacco | | |
| Cooking in dining cars and restaurants | | Heating salamanders in shipyards and citrus groves |
| METALLURGICAL PROCESSING AND PRODUCTION: | | |
| Copper | Steel | Electro manganese |
| Brass | Nickel | Armor plate |
| Pig iron | Aluminum | Foundry molds |
| CHEMICAL PROCESSING AND PRODUCTION: | | |
| Carbon disulfide | | Plastics |
| Calcium carbide | | Fireworks |
| Silicon carbide | | Rubber |
| Sodium cyanide | | Gas adsorbent |
| Potassium cyanide | | Crayons |
| Carbon monoxide | | Soil conditioner |
| Activated carbon | | Pharmaceuticals |
| Black powder | | Poultry and animal feed |

Table 43. — Consumption of frothers in froth flotation of ores, 1960 (adapted from Fuerstenau 1962)

| Type of frother | Arizona and New Mexico | Colorado and Utah |
|---|---|---|
| | Pounds | |
| Aerofroths | 218,493 | 6,364 |
| Creosote oil | 1,520,190 | ([1]) |
| Cresylic acid | 2,048,735 | 708,621 |
| Dow froth | 406,493 | 12,604 |
| Methyl amyl alcohol | 1,086,029 | 1,734,694 |
| Methyl isobutyl carbinol | 932,814 | 40,715 |
| Pine oil | 1,524,454 | 380,228 |
| Total | 7,737,208 | 2,883,226+ |

[1] Suppressed to avoid disclosing individual company data.

Table 44. — Chemical components of the volatile leaf oils of creeping juniper, Rocky Mountain juniper, and savin juniper, identified by gas chromatography (adapted from Couchman and Von Rudloff 1965, Von Rudloff and Couchman 1964, and Von Rudloff 1963)[1]

| Chemical component | Creeping juniper | Rocky Mountain juniper | Savin juniper |
|---|---|---|---|
| | Percent | | |
| Sabinene | 36.5 | 45.7 | 30.5 |
| Limonene | 17.5 | 11.4 | 1.6 |
| Terpinen-4-o1 | 4.6 | 2.9 | 2.0 |
| α-Pinene | 1.6 | 4.2 | 2.2 |
| β-Pinene | 0.3 | - | - |
| Sabinyl acetate | - | - | 38.0 |
| Acetate II | 0.5 | 4.7 | - |
| Cadinene, Cadinene I, Cadinene II | 1.6 | 2.7 | 4.5 |
| γ-Cadinene | 1.3 | - | - |
| Cadinene isomer | - | - | 0.3 |
| Elemol | 3.8 | 6.0 | 0.5 |
| Elemene | - | 0.3 | - |
| Myrcene | 3.0 | - | 4.5 |
| Safrole | - | 1.9 | - |
| Sabinol | - | - | 0.9 |
| γ-Terpinene | 0.4 | 1.2 | 0.7 |
| ρ-Cymene | 3.0 | 1.4 | 0.4 |
| Linalool | 0.8 | 1.2 | - |
| α-Cadinol or γ-eudesmol | 1.6 | - | - |
| α-Cyperone | 3.9 | - | - |
| Citronellol | 0.8 | 0.2 | 1.8 |
| Methyl citronellate | - | - | 1.7 |
| Isothujone | - | - | 0.5 |

[1]Not included are trace components tentatively identified by relative retention time only.

Table 45. — U.S. standards for grades of Christmas trees (adapted from U.S. Department of Agriculture 1962)

| Grade and general condition | Taper | Allowable damage |
| --- | --- | --- |
| U. S. PREMIUM<br>Fresh, clean, healthy, well trimmed, medium or better density | Normal | Four faces free from damage |
| U.S. NO. 1 OR U.S. CHOICE<br>Fresh, clean, healthy, well trimmed, medium or better density | Normal | Three faces free from damage |
| U.S. NO. 2 OR U.S. STANDARD<br>Fresh, clean, healthy, well trimmed, light or better density | Candle-stick, normal, or flaring | Two adjacent faces free from damage |
| CULL<br>Fails to meet requirements for the U.S. No. 2 (standard) grade | | |

## COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

| | |
|---|---|
| Cactus | *Opuntia* spp. |
| Douglas-fir | *Pseudotsuga* spp. |
| Hickory | *Carya* spp. |
| Juniper, alligator | *Juniperus deppeana* Steud. |
| Juniper, alligator (Texas) | *Juniperus mexicana* Scheide & Deppe (synonymous with *J. deppeana*) |
| Juniper, creeping | *Juniperus horizontalis* Moench. |
| Juniper, one-seed | *Juniperus monosperma* (Engelm.) Sarg. |
| Juniper, Rocky Mountain | *Juniperus scopulorum* Sarg. |
| Juniper, savin | *Juniperus sabina* L. |
| Juniper, Utah | *Juniperus osteosperma* (Torr.) Little |
| Juniper, western (or Sierra) | *Juniperus occidentalis* Hooker |
| Mesquite | *Prosopis juliflora* (Sw.)DC. |
| Oak | *Quercus* spp. |
| Oak, Arizona white | *Quercus arizonica* Sarg. |
| Oak, Emory | *Quercus emoryi* Torr. |
| Oak, Gambel | *Quercus gambelii* Nutt. |
| Pine, ponderosa | *Pinus ponderosa* Laws. |
| Pinyon, common | *Pinus edulis* Engelm. |
| Pinyon, Mexican | *Pinus cembroides* Zucc. |
| Pinyon, singleleaf | *Pinus monophylla* Torr. & Frém. |
| Redcedar, eastern | *Juniperus virginiana* L. |
| Sagebrush | *Artemisia* spp. |
| White-cedar, northern | *Thuja occidentalis* L. |

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Barger, Roland L. and Peter F. Ffolliott.
1972. The physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Serv. Res. Pap. RM-83, 80 p. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 80521.

Woodland species, principally pinyon and juniper, cover over 51 million acres in Arizona and adjoining States. The occurrence, physical characteristics, and utilization potential of pinyon, juniper, and Gambel oak are reported here. Products for which they may be especially suited include veneer, particleboards, charcoal, pulp, and chemical extractives. In addition, pinyon is valuable for Christmas trees and nuts.

The report is a reference handbook of all available information relating to stand and stocking characteristics and physical and chemical properties of the species.

Key words: Woodland species, pinyon-juniper, forest products, wood properties.

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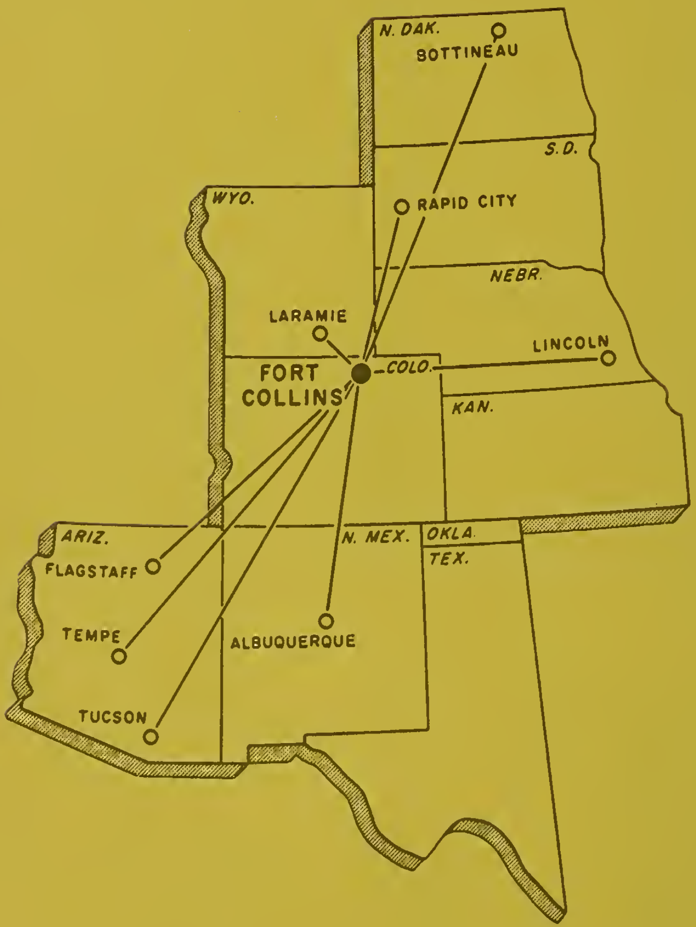
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